EVALUATION OF PROGRESSION OF KERATOCONUS USING PENTACAM

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CERTIFICATE

This is to certify that this dissertation entitled **"EVALUATION OF PROGRESSION OF KERATOCONUS USING PENTACAM"** is a bonafide done by **Dr. SUNDAR. T** under the guidance and supervision in the department of the cornea, Aravind Eye Hospital and Post Graduate Institute of Ophthalmology in Madurai during his residency period from May 2012 to April 2015.

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DECLARATION

I **Dr. SUNDAR .T** solemnly declare the dissertation titled **"EVALUATION OF PROGRESSION OF KERATOCONUS USING PENTACAM"** has been prepared by me. I also declare that this bonafide work or a part of this work was not submitted by me or any other for any award, degree, diploma to any other university board either in India or aboard

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CONTENT

INTRODUCTION

Keratoconus is a bilateral, non-inflammatory, asymmetric progressive axial thinning disorder of the cornea in which the cornea assumes an irregular conical shape[1]. Keratoconus is a degenerative disorder of the eye in which structural changes within the cornea cause it to thin and change to a more conical shape than its normal gradual curve. The word keratoconus is derived from greek word kerato-cornea, konos-cone[2]. The hallmark of keratoconus is central or paracentral stromal thinning, apical protrusion and irregular astigmatism[1]. Corneal protrusion causes high myopia and irregular astigmatism affecting visual acuity. Onset of keratoconus occurs immediately after puberty with mean age of onset being 16 years[3] however, onset has been reported to occur as early as 6 years of age[4]. Keratoconus rarely develops after 30 years of age[5]. Keratoconus shows no gender predilection and is bilateral over 90% of cases[6]. It also causes significant impairment in both the quantity and quality of vision because of the progressive nature of the disease[1]. We are planning to use the new (pentacam system) elevation based approach to increase sensitivity to detect early progression, in eyes from patients previously diagnosed with unilateral and bilateral keratoconus.

HISTORY OF KERATOCONUS

The description of keratoconus was made in 18th century by Mauchart, describing the condition as staphyloma diaphanum[7,8] , but it was a British physician John Nottingham first described and distinguished keratoconus from other types of corneal ectasia[8,9]. The disorder acquired its current name from the Swiss ophthalmologist Johann Horner who published a thesis entitled " *On the treatment of keratoconus"* in 1869[10]. The early treatment of keratoconus consist of using silver nitrate and cauterizing the ectatic area of cornea and it was in 1888, Eugene Kalt, a French ophthalmologist, described the first application of contact lens using a crude glass shell to compress the conical apex in keratoconus[11].

EPIDEMIOLOGY:

The incidence of keratoconus is being 50 to 230 per 1,00,000 (approximately 1 per 2,000) in the general population[12]. Keratoconus in India presents at a younger age than in the western population and progresses more rapidly. Earlier age of onset has been associated with a significantly higher need for surgery possibly because of more rapid

progression. Keratoconus affects both genders, although it is unclear whether significant differences between males and females exist. Some studies have not found differences in the prevalence between genders but others have found a greater prevalence in females, while some other investigators have found a greater prevalence in males[13].

ETIOPATHOGENESIS

Etiology is multi-factorial. Both genetic and environmental factors are associated with keratoconus. The role of heredity is not clear because most patients do not have a positive family history. Off springs appear to be affected in only about 10% of cases. Autosomal dominant transmission with incomplete penetrance has been proposed. There is an increasing data suggesting that the environment might also play a role in the development of this condition, the disease is common in dry and cold climates[1]. Recent studies suggest that enzyme abnormalities in the corneal epithelium, such as increased expression of lysosomal enzymes and decreased levels of inhibition of proteolytic enzymes may play a role in corneal stromal degradation. Eye rubbing, contact lens wear may play a role. The interleukin-1 has been suggested as a mediator of eye rubbing and stromal degradation. Keratoconus affects all the layer of cornea[7]. Basal epithelial cells degeneration occurs in the epithelium and the Bowman's layer which Leads to basement membrane disruption and further creates break in the Bowman's layer which leads to scarring of Bowman's layer and the anterior stroma. Stromal thinning is due to reduction in number of collagen fibres. Endothelium shows pleomorphism and polymegathism of endothelial cells.

Degeneration of basal epithelial cells

⇩

Disruption of the basement membrane

⇩

Growth of epithelium posterior to the Bowman's layer and collagen anterior to the epithelium

⇩

Z-shaped interruptions or breaks in the Bowman's layer

⇩

Scarring of the Bowman's layer and the anterior stroma

Natural course of the disorder:

The disease Process continues to progress over a period of 10-20 years and stops. The severity ranges from mild irregular astigmatism to serve thinning and apical protrusion requiring penetrating keratoplasty [14]. The rate of progression and the length of time of that entity remains actively progressive tend to vary considerably. The ectasia progresses slowly and then stabilizes permanently. It is uncommon for this condition to progress beyond 40 years of age. Occasionally progression

remains arrested at an early stage resulting in forme-fruste keratoconus. As keratoconus progresses, corneal curvature typically steepens.

ANATOMY OF CORNEA AND ITS OPTICS

Cornea is the most powerful refractive element of the eye[15] which contributes to about 43 D (70%) of refractive power to the eye out of the total 60D. As the refractive power is determined by the shape of the corneal surface, even a minor modification on its surface can lead to significant alteration of the images formed on the retina.

Corneal Dimensions:

The anterior surface of cornea is elliptical with an average horizontal diameter of 11.5 mm vertical diameter of 10. 6 mm. The posterior surface of cornea is circular with an average diameter of 11.5mm. The corneal thickness varies from 0.52mm at the centre to 0.67mm peripherally and about 1.2mm at the limbus.

The normal human cornea is both aspherical and variable in curvature. It has got different radii of curvature . It has got different radii of curvature at different points along the same meridian with central steepening and peripheral flattening giving a prolate surface. Asphericity varies even among different meridian of the same cornea. The anterior

and posterior radii of curcature of the central optic zone of cornea are approximately 7.8mm and 6.5mm respectively. The average corneal power is 48.6 D anteriorly and -6.8 D posteriorly. Therefore the net refractive power of cornea comes to about 43 D. By 30 years of age it flattens about 0.5 D and by age 70 years it steepens about 1 D.

Optical Zones Of Cornea:

For practical and functional purpose, the surface of the cornea can be divided into four regions [16]:

- Central Zone
- Paracentral Zone
- Peripheral Zone
- Limbal Zone

a) Central Zone:

It is approximately 4 mm in diameter and is responsible for formation of image at fovea. It is also called the apical zone or corneal cap. It is more spherical, symmetrical and optically important. Here the radius of curvature does not vary by more than

1 D or 0.05mm and hence the difference in refraction will be less than 0.25 d.

b) Paracentral Zone:

It has approximate diameter of 4-8mm. It is mostly spherical but compared to central zone it is slightly flatter. Along the central zone it forms the optical zone of the cornea. The curvature of this zone markedly changes after radial keratotomy. Its topography becomes important in conditions of dim illumination when the pupil is dilated.

c) Peripheral Zone:

The diameter is about 8-11mm. Here the cornea flattens more, thereby increasing the asphericity.

d) Limbal Zone:

It forms the corneal rim. It has a width of about 0.5mm at an average which about the sclera. Changes in dimension of this zone because of surgery can influence the shape of the central regions of cornea.

Planes And Meridia Of Cornea:

The introduction of multiple planes intersection through the cornea can convert the cornea from a three dimensional structure to a two dimensional one.

They are as follows

a) **Meridional plane:**

A plane through the centre of the cornea is called a meridional plane or tangential plane. They are specified coordinates with the origin at the centre, the angular position of 0 degree at the 3' o clock position and the angles increasing in a counter clock wise manner.

b) **Corneal Meridia:**

These are the intersection of meridional planes with the corneal surface and cover angular position from 0 degrees to 180 degrees.

c) Hemimeridia:

They are also called semimeridia and are defined from the centre outwards and cover angular positions from 0 degrees to 360 degrees.

d) Sagittal Planes:

The sagittal planes or transverse planes complete the three dimension of the corneal structure. Its intersection at a surface point is perpendicular to the meridional plane through that point and contains the surface normal.

Axis Distance Surface Height And Refractive Axis:

Axis Distance :

It reference to the distance from a point on a curve to the reference axis along for the surface normal at the point[17]. For a cirrcleor sphere the axial distance and radii of curvature are all identical. Axial distance can be converted into a diopteric value for topographic interpretation. This can be done with the fourmala Da = 9n-1)d where Da is axial diopetres, d is axial distance, n and 1 are the indices of refraction of keratometry and

air respectively. These axial distance based maps are useful for refractive power display in corneal topography.

Surface height:

It is the actural elevation of the corneal surface relative to a reference. The reference can be a plane tangent to the apex or a best-fit reference sphere. The surface height relative to a reference gives more clinical information in corneal topography. It determines the creation of colour coded maps. With reference to the surface height, an intermedicate colour is chosen depict the netural position. Then the elevation above and below are graded accordingly.

Reference axis:

It defines the centre of topographic display and thus the meridional planes in which axial shape and curvature are determined. Depending on the type of application of corneal topography the axis appropriate for the centre can be selected.

Characteristics Of Cornea:

The geometrical and optical properties are some of the important characteristics of the cornea. The gross anatomy of the cornea is demonstrated by the geometrical property which is very basic. The concept of how light is refracted through the surface of the cornea is demonstrated by the optical property. It is an intrinsic property. Among the geometrical properties of the cornea, the diameter and thickness of the cornea are considered the most important. The depth of ablation to be covered by an excimer laser during a refractive surgery can be calculated from a theoretical formula called the munnerlyn formula[4] which was discovered by Charles Munnerlyn. The formula states that the depth of ablation (in micrometers) per dioptre of refractive changes is equal to the square of the diameter of the optical zone measured in millimeters, divided by the three[18].

For example to change the refraction of cornea by 4 dioptres in an optical zone of 3mm, the depth of ablation required would be 12 micrometers. To change the refraction by the same 4 dioptres in a optical zone of 6mm, the depth of ablation required would be around 48 micrometers. This is because the ablation depth is directly proportional

to the square of the optical zone. It is to be noted that the depth of ablation will not take into account the transition zone of surgery. Hence the actual depth of ablation and surface of the cornea will be slightly different as when compared to the theoretical Munnerlyn formula[18]. The surgery is also influenced by many other factors like the sex, age and the race of the patient. Even factors like the barometric pressure and ambient humidity will change the required depth of ablation slightly.

The important optical properties of the cornea include the curvature and the angle kappa[4]. The amount of corneal astigmatism is determined by the curvature. Angle kappa is the angle formed between this visual axis and the anatomic papillary axis of the eye. The measurement of this angle can be made by Hirschberg test. This test is based on the location of the corneal light reflix. Because of the temporal displacement of the fovea from the papillary axis, the corneal reflex falls around 0.5mm nasal to the center of the cornea. The Hirschberg test is considered to be positive if the corneal reflex does not fall on this location. The orbscan topography can measure the location of corneal reflex exactly in relation to the x-y axis. There must be knowledge of the normal findings of the cornea in order to defect any abnormality. Depending on factors like the

age and race of the population, the normal corneal characteristics actually vary from one another. Any finding which falls out of the normal range requires caution ad misinterpreting it can lead to grave complications.

The curvature of the corneal anterior and posterior surfaces can be expressed as radii of curvature in millimeters. This expressed clinically in keratometric dioptres. The shape of the anterior surface and posterior surface can also be shown in micrometers as the elevation of the actulal surface relative to a chosen reference surface of example, a sphere. The overall shape and major irregularities of the surface of the cornea such as the corneal astigmatism are characterized by these two concepts. The corneal power is expressed as refraction in terms of dioptres. It is an optical property and depends on the surface shape and the refractive index of the surface[16].

The keratometric dioptre is based on derivations from keratometry. It is calculated from the radii of curvature as given below:

K= Refractive index of 333.5/ Radius of curvature.

This derivation is a simplified way and ignores the fact that the air-tear interface is the refracting surface. It does not take into account the oblique incidence of incoming light in the periphery of the cornea. Therefore it performs a miscalculation of a true corneal refractive index of 1.376 to 1.3375 in order to correct the above factors. Hence to differentiate from the dioptres depicting the true refractive power at a certain corneal point, these dioptres are called as the keratometric dioptres.

KERATOCONUS CLASSIFICATION

On the basis of Radius of Curvature of anterior segment of cornea[19]

1. Mild(early)- 8.00-7.00mm(42-47D)
2. Moderate – 6.90-6.50mm(47-52D)
3. Advanced- 6.40-6.00mm(53-56D)
4. Severe - <6.00 mm(>57D)

Keratoconus cones can be classified as[19]:

1. Nipple- smaller diameter (5mm), cone lies in the lower nasal quadrant.
2. Oval-larger diameter (>5mm), cone lies in the infero-temporal quadrant.
3. Globus-largest diameter (>6mm), 75% of the cornea is affected.

ASSOCIATIONS OF KERATOCONUS

- **Systemic associations:**

  Down's syndrome

  Ehlers-Danlos syndrome

  Osteogenesis Imperfecta

  Marfan's syndrome

  Crouzon's syndrome

  Laurence Moon Bardet Biedl syndrome

  Nail patella syndrome

  Neurofibromatosis

  Pseudoxanthoma elasticum

  Turner's syndrome

  Xeroderma pigmentosa

Ocular Associations

- **Corneal disorders:**

  Atopic keratoconjunctivitis

  Axenfeld's anomaly

  Corneal amyloidosis

  Essential iris atrophy

Fuch’s corneal dystrophy

Microcornea

Lattice dystrophy

- **Non corneal disorders:**

Retinitis Pigmentosa

Vernal conjunctivitis

Leber’s Congenital Amaurosis

Gyrate atrophy

Aniridia

Congenital Cataract

Ectopialentis

Lenticonus

Macular coloboma

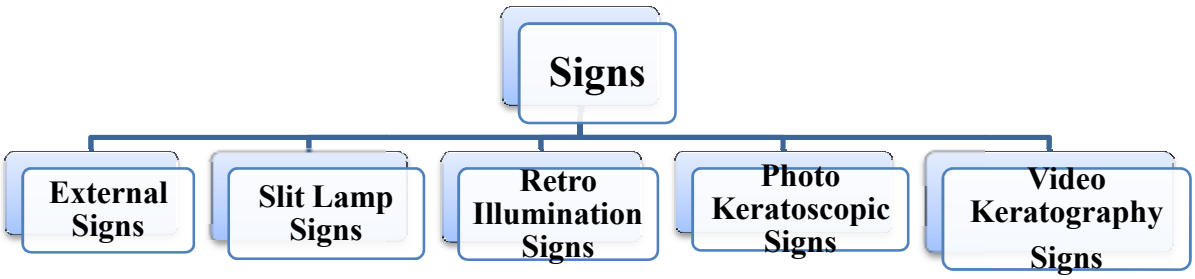
Retinal dysplasia

Floppy eyelid syndrome

CLINICAL PRESENTATION

The corneal thinning in a keratoconus patient induces irregular astigmatism, myopia and protrusion leading to a marked impairment in the visual acuity. It is a progressive disorder ultimately affecting both the eyes. Symptoms are highly variable depending on stage of the disease. Early in the disease there may be no symptoms. In advanced disease, there is a significant distortion of vision accompanied by profound visual loss.

Signs: [20]



External signs:

- Munson's sign: In advance cases of keratoconus, there is indentation of lower lid, caused by the protruding apex when patient is asked to look down
- Rizutti's sign: In Keratoconus patients with high astigmatism and steep curvatures, when light is shown from temporal side, reflex will be displaced beyond the nasal limbus.

Slit Lamp Signs:

- Vogt's Striae - These are fine vertical stress lines in the deep stroma which disappears temporarily on digital pressure.
- Fleischer Ring - It is the deposition of iron in the basal epithelial cells. This ring is faint in early Keratoconus and becomes thinner and more discrete as the condition advances.
- Prominent Corneal nerves- It is not likely that the nerve fibres are more numerous in keratoconic patients, but only that they are more easily seen due to changes in density.

- Corneal apical scarring - Patients with moderate Keratoconus develop corneal apical scarring. It occurs as a part of natural progression of the disease but worsened by wearing of rigid contact lens.

- Acute Hydrops- It is due to sudden rupture in the descemet's membrane and the endothelium that is overlying leads to imbibitions of aqueous into the corneal stroma through the rupture decimal membrane causes stromal swelling (stromal edema) with overlying epithelial edema(bullae).

Retro illumination Signs:

- Scissoring reflex on retinoscopy- This reflex appreciated well when pupil is dilated. It is produced because of the presences of two conjugate foci in the axis of pupil and high irregular astigmatism. The central part of cone is hypermetropic compared to myopic periphery. During retinoscopy, at the point of neutralisation the central zone produces the reflex that moves with the streak due to hypermetropia and peripheral zone produces a reflux that

moves against the streak due to myopia which produces scissoring reflex.

- Oil droplet sign (Charleaux Sign) - This sign in noticed on distant direct Ophthalmoscopy**.** It is seen with dilated fundus examination. Annular dark shadow separates bright reflex of central and peripheral areas. This occurs due to total internal reflection of light

Photokeratoscopic Signs:

- Compression of Mires infero-temporally (egg-shaped mires).
- Compression of mires inferiorly or centrally.

Videokeratography Signs:

- Localized increase of surface power which is usually present in the interior or infer temporal cornea.
- Inferior superior diopteric asymmetry.

- Relative skewing of steepest radial axes above and below the horizontal meridian.

Symptoms:

- Deteriorating visual acuity, distortions, glare
- Frequent changes in refraction
- Visual acuity not refractable to 6/6
- Monocular polyopia or ghosting.

Modified Krumeich classification of keratoconus:

Stage	Characteristics
I	Eccentric corneal steepening Induced myopia /astigmatism<5D Corneal radii≤48D Vogt's striae, no scars
II	Induced myopia and/or astigmatism>5D,< 8 D Corneal radii ≤53D No central scars Corneal thickness ≥400 μm
III	Induced myopia and/or astigmatism>8D, <10D Corneal radii>53D No central scars Corneal thickness200—400 μm
IV	Refraction not measurable Corneal radii >55D Central scars, perforation Corneal thickness<200 μm

DIAGNOSIS

Diagnosis of Keratoconus is done by careful refraction, slit lamp biomicroscopy, keratometry and corneal topography.

- **Keratometry:** The keratometry mires commonly are steep, high astigmatic, irregular, and often appear egg-shaped rather than circular or oval. It also shows increased keratometry values typically between 45 to 52D or more, which are also used to grade the severity of Keratoconus.

- **Videokeratography:** It commonly shows inferior corneal steeping in keratoconus, although a small percentage of patients show central astigmatic changes. An even smaller number of patients may show superior steepening.

IMAGING IN KERATOCONUS[21,22,23]:

- Photographic Placido disc
- Keratometry
- Photokeratoscopy
- Computer assisted video keratoscopy
- Elevation based topography

Photographic Placido disc

Antonio placido who first developed this instrument so it is known as placido disc. It consists of alternating white and black rings which are equally spaced with a hole in the center. Through the hole patient's cornea is observed. The shape of the cornea is distorted when there is any deviations in the evenly spaced concentric circles. This method is only a qualitative evaluation of the corneal shape.

Limitations:

- Abnormalities of small degrees in corneal shape are not easily distinguished.
- Conditions like corneal epithelial defects and corneal opacities, placido disc cannot be used due to non reflection of the target by the cornea.

Keratometry

This device mainly used for the measurement of dimensions of the eye. Helmholtz and javal modified this device mainly for the measurement of curvature of the anterior corneal surface. The principle of keratometry is essential for cornea topographic analysis. Along the orthogonal meridian of the anterior corneal surface two pairs of fixed points are reflected in the paracentral zone. The are separated by 3mm approximately. The measured distance between these two pairs is used by keratometry. The device projects an illuminated target on the surface of the cornea from a distance fixed based on the focus and alignment. By comparing the diameters which are measured on the calibration spheres the maximum and minimum diameters of the reflected images can be determined. These measurements provide the radius of curvature of the central cornea and also the amount and axis of any astigmatism if it is present. Keratometry is routinely used in contact lens fitting and in preoperative calculation of intraocular lens power to visually rehabilitate an aphakic eye. It is reasonably reliable for the accurate measurement of corneal contours.

Limitations:

- It does not provide any useful data of the corneal surface either in central or peripheral zones.
- It assumes that cornea is either sphere or spherocylinder, but the normal cornea is mostly aspheric and asymmetrical. So keratometer not used in the measurement of the cornea that are different from a sphere or spherocylinder.

Photokeratoscopy

When a photographic film camera is attached to a keratoscope it is called photokeratoscope. A record or portrayal of corneal surface produced by the photographic film is called a keratograph. In 1896 gullstrand provided precise methods for quantitative analyses. In this technique, Keratoscopic image is photographed and the size of the images on the photographic film can be varied to change the size of the corneal image. The corneal curvature is then measured using the distance of the keratoscopic rings from the cornea. The magnification of the virtual image formed by the anterior corneal surface and the focal length of the objectives of the camera. The image of most photokeratoscopic rings cover the paracentral zone with overlapping of the central and peripheral

zones. Therefore the optically important central 2 to 3 mm zone is not covered. In the photographics if the lines are closer it indicates a steeper cornea and if the lines further apart it indicates a flatter cornea. Hower corneal cylinders upto 3 D can be missed by this technique.

Computer assisted videokeratoscopy

When a television camera is attached to a keratoscope it is called videokeratoscopy. It has been computerized in recent times. The common topographers used nowadays are based on principles of placido disc. Though many such devices are currently available elevation based topography is mostly used. These instruments primarily consist of either a placido disc-type nose cone or large placido disc consisting of different number of dark and light rings and sometimes Colours. Central camera captures a placido disc image that is reflected from thin tear film on the cornea into system based on computer. This computer based system analyzes the data. A scan of good quality gives accurate measurements of corneal curvature and the pre-requisites for a good scan are,

1. Stable tear film
2. Good patient fixation
3. Adequate exposure of cornea
4. Superior and inferior quadrants of cornea not obscured by lids.

TOPOGRAPHIC SCALES

The following colours are true for most of the “standard” scales. But different topographers use different steps of Colours, hence comparing two different topographers is difficult.

Red and orange colours on the map are considered warmer colours and they indicate steep cornea with high keratometric diopteric power.

Violet and blue Colours are considered cooler colours and they indicate flat cornea with low diopteric power, Green and yellow indicate Colours found in the normal cornea. Topography of same cornea may look different with change in steps of the Colour. Smaller steps help to increase the sensitivity to identify early keratoconus, however it can diagnose a normal cornea falsely as keratoconus, whereas larger steps of colours may miss out the early changes. Hence, the topography must not be evaluated only based on Colours.

Absolute or standardized scale:

Absolute scale map has a fixed Colour-coding system for that particular instrument. Same colours always represent same diopteric steps, minimal and maximal diopters. These maps taken over a period of time are good for direct comparison to analyze the progression of keratoconus and to detect gross pathologies. However, the colour steps are in large increments (some 0.5 D and others 1.5 D)and the disadvantage is that subtle changes of curvature are not identified and subtle local changes like early keratoconus can be missed.

Normalized or relative scale:

These maps have different Colour scales that are assigned to each map. Here computer identifies the minimal and maximal dioptric values in the map and distributes the range of Colours automatically. According to the range in a given cornea, computer contracts or expands its range of colours. Advantage of normalized map is that it shows more topographic details because dioptric range assigned to every Colour is smaller when compared to the absolute map. Disadvantage is that Colours of the different maps from even the same cornea cannot be compared directly because they have different steps. A normal cornea may have different

Colour and if interpreted only based on the Colours it may look abnormal.

Topographic pseudokeratoconus[1]:

Contact lens wear is the common culprit (both soft and hard) for this condition. Contact lens wear induces inferior steepening pattern that is difficult to distinguish from keratoconus. However such patterns disappear when contact lens wear is stopped. Topographic pseudokeratoconus can result from technical errors during the procedure such as compression of inferior eyeball while retracting the eye lids, misalignment of eye due to inferior or superior rotation of eye ball, incomplete mires digitization, dry spots formation that simulates inferior steepening. Conditions like pellucid marginal degeneration, Terrien's marginal degeneration, keratoglobus, corneal scar , previous ocular surgery can also cause inferior steepening.

CURVATURE/POWER MAP:

Axial curvature map or sagittal curvature map:

Most commonly used map.This map measures the curvature at a certain point on the surface of cornea in axial direction relative to center. It helps in evaluating overall corneal shape. The advantage of the map is that pattern diagnosis of the map can be done and the map can be distinguished into normal or abnormal. Typical topographic pattern of diseases is used to identify them easily. For example: keratoconus has asymmetric bow tie pattern and skewing of radial axis and pellucid marginal degeneration has “butterfly” or “crab-claw” pattern. Disadvantages are of the map are inaccurate measurement of peripheral curvature and smaller or local irregularity can be missed.

Tangential curvature map or instantaneous map or meridional curvature map:

This map measures the curvature on the surface of cornea at a certain point in a meridional direction relative to other points on the particular ring. Tangential curvature maps are very sensitive in detecting local change of corneal curvature, hence useful in detecting early changes that could have been missed by axial map. Tangential curvature maps are more accurate than the axial map in periphery of cornea. The

disadvantage is that it is subjected to variations because it detects localized changes and so for the same disease similar topography may not be obtained making pattern diagnosis difficult.

Elevation map:

Placido based topographs not measures the elevation directly. However, certain assumptions lead to the construction of elevation maps. Elevation of a point on the surface of the cornea displays the height of the point (in micron) on the corneal surface relative to a reference surface. This reference surface in most of the instruments is a sphere. Some systems also allow various other shapes like ellipsoid, toric ellipsoid, torus as reference surface. The best mathematical approximation of actual surface of cornea is called best-fit sphere(BFS) and is calculated using instrument software for each elevation map separately. Also in the same individual, size or radius of curvature of the BFS might differ from test to test. When mapped against different surfaces of reference the same surface may appear different. Hence, direct comparison of two elevation maps that have slight difference in BFSs as reference values is difficult and comparison can only be intuitive. Some elevation based topographers have an option of changing and matching the radius of curvature of the BFS of two different maps. It is also important to check for the scan

quality using their raw data or “Quality Score”. Direct comparison of two maps requires x-y alignment of the two maps, and a few elevation based topographers are capable of doing this.

Statistical Indices:

Common indices are:

1. Simulated keratometry (SimK): Equivalent to keratometry and is calculated at steepest axes and at 90° to the steepest axes from the average power at the central 3 mm zone. Difference is calculated as cylinder (Cyl). Flattest axes (MinK) can also be measured.

2. Surface asymmetry index (SAI): Difference in corneal power on the same ring between points that are 180° apart, that quantifies progression of keratoconus.

3. Surface regularity index (SRI): Points that are in the central 4.5 mm are compared with the surrounding points. Presence of high values suggest high irregularity in the corneal surface.

4. Inferior-superior value (I-SV): Calculated from the difference of power between five superior points and five inferior points 3 mm from center at intervals of 30 degrees.

5. Other indices specific for each instrument do exist. Example: corneal uniformity index (CUI), Point spread function(PSF), Predicted corneal acuity (PCA). Patients with normal corneal indices may have poor vision due to disturbances in any other part of the eye.

Corneal OCT[24]:

Corneal thickness (pachymetry) measurement has important applications related to diagnosis and surgery in keratoconus and other corneal ectasias. The Ocular Coherence Tomography is a noncontact modality for imaging which provides cross-sectional analysis of corneal thickness with high resolution. Though OCT scanners of retina can measure central corneal thickness, due to slow scanning speed and motion artefacts pachymetric mapping is not possible. Corneal OCT provides a precise pachymetric map, unlike ultrasound pachymeters which provides only spot pachymetry.The five OCT parameters in

pachymetry which shows high sensitivity and specificity in diagnosis of established keratoconus are:

1. Minimum-median – A cut off value of 62.6 μ

2. The I-S: Difference of average thickness of inferior (I) octant and superior(S) octant (A cut off value of 31.3μ).

3. The IT-SN: Difference of average thickness of IT octant and SN octant (A cut off value of 48.2μ).

4. Minimum thickness (A cutoff value of 491.6 microns).

5. Vertical location of the minimum. Locations superior to vertex of cornea - positive values, locations inferior to vertex of cornea -negative values (A cut off value of 716 μ).

With Fourier domain OCT, epithelial thickness profile maps have been recently used to detect subtle changes in epithelium, a sign of early keratoconus. Thinning of epithelium over the corneal apex in early ectasias may mask the topographic changes on anterior surface of cornea. In the past, ultrasound of high frequency was used to demonstrate precise

epithelial thickness profiles which were useful in diagnosing keratoconus at an early stage. However Fourier domain OCT provides a simpler and noninvasive method to perform corneal epithelial analysis.

The OCT is also useful in studying optical characteristics of cornea after surgical interventions like collagen cross-linking. After cross-linking:

1. First few weeks - faint hyper reflectivity in anterior stroma.
2. Around 1 month - distinct demarcation between cross-linked and the non-cross-linked areas of cornea is noted.
3. By 3 months - demarcation line fades and is sometimes replaced with faint irregular hyper reflective lines in deeper stroma.

In previous cases of hydrops, OCT is extremely useful to identify Descement's membrane irregularity and helps in deciding about deep anterior lamellar keratoplasty. Hand held OCT with high resolution is a useful tool to identify the extent of residual cornea in cases that underwent lamellar keratoplasty. OCT also shows the corneal stroma that is posterior to intracorneal ring segments. OCT in cases of post

keratoplasty helps us to study the architecture of wound and wound apposition posteriorly and suture removal can be decided.

ELEVATION BASED TOPOGRAPHY

There are two basic types of topography

- Orbscan- scanning slit based elevation topographer.
- Pentacam- Scheimpflug based elevation topographer.

Orbscan:

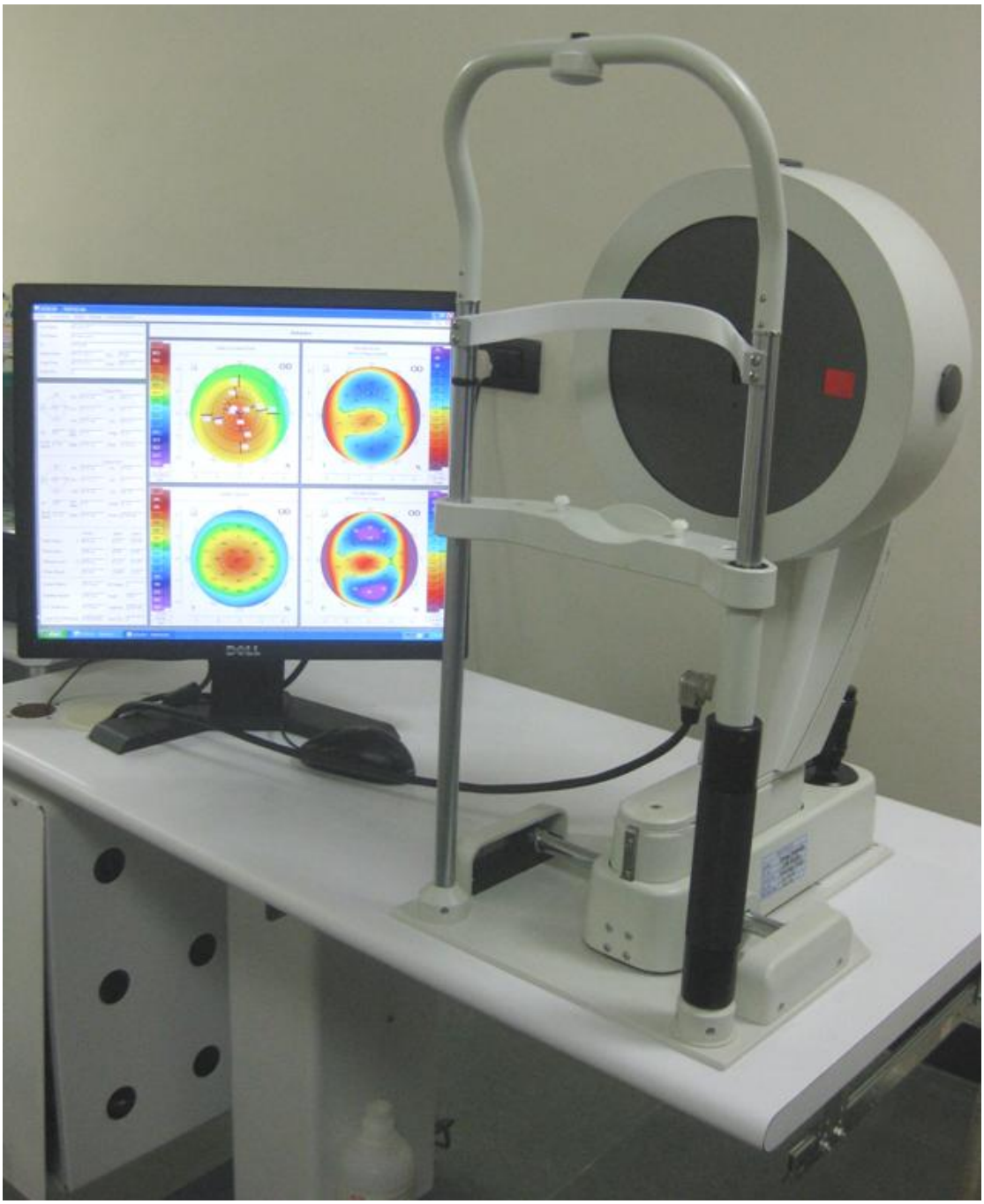
Orbscan is based on scanning slit beam with a placido disc. The first orbscan based on slit scanning beam projected on the cornea. Then in 1999 orbscan IIz added a placido image to obtain curvature measurements directly. Data points from the reflection of the mires and 20 slit scans are used to make a representation of the anterior surfaces of the cornea. The principle of this scanning slit based topography is similar to the slit lamp corneal topography which uses slit scan optical pachymetry to determine the z axis, elevation and posterior surfaces of the cornea. An image of slit light intersecting the cornea is used to obtain localized impression of the profile of both corneal surfaces. Two slits positioned at an angle of 45 degree to right and left of instrument axis. 20 images are captured from each direction to obtain information from the cornea.

Limitations:

Inability to detect interfaces (eg: after LASIK flap) and the longer time of image acquisition and processing compared to standard Placido-based topography.

Placido scanning optical slit design and Scheimpflug imaging serves the most important tool for recording progression and diagnosis of keratoconus. Though Placido based devices are highly sensitive in diagnosing curvature changes on the anterior surface of cornea, they might miss early posterior corneal ectatic changes but Pentacam system which is based on Scheimpflug technique provides standardised indices for ectasia detection. Major benefit of this pentacam imaging technique is the measurement of posterior corneal surface. Posterior cornea which is an earlier indicator of ectatic change when combined with full pachymetry data serves as a more sensitive screening tool than anterior topography and ultrasound pachymetry combined.

Pentacam[25]:



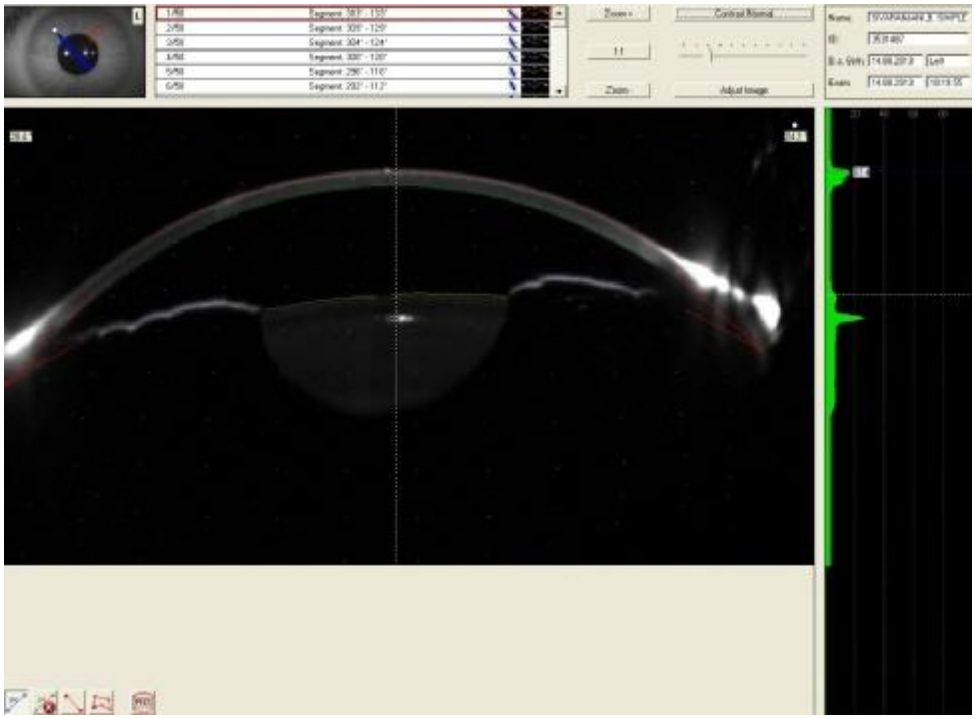
The Oculus Pentacam has a rotating Scheimpflug camera. Due to the rotation, the dot matrix meshed in the centre, the rotating camera produces three dimension scheimpflug image. To generate a complete image of the anterior segment the camera takes a maximum of 2 seconds. If there is any eye movement during the procedure it will be detected by the second camera and corrected for in the process. " The Pentacam calculates a three dimensional model of the anterior eye segment for as many as 25000 true elevation points" The center of the cornea is measured very precisely because of this rotational imaging process. The corneal thickness is displayed as a colour image, showing the entire area from limbus to limbus. Anterior segment analysis includes the calculation of the anterior chamber's angle, volume and height. The images of the anterior and posterior corneal surface, iris, anterior and posterior surface of the lens are generated in a virtual eye. The densitometry of the lens is automatically quantified. During the examination the scheimpflug images taken which are digitalized in the main unit and all the image data are transferred to the personal computer (PC). When the examination is over, the PC calculates a three dimentional virtual model of the anterior eye segment, from which all additional information is derived.

50 Scheimpflug Images

New High Resolution (HR) Pentacam[26]

The new(HR) pentacam which captures 100 images in less than 2 seconds. It provides higher resolution of 1.45mega pixel camera. It gives sharper scheimpflug images which helps in imaging more detailed IOL and phakic IOL. Additionally it provides more precise imaging of corneal layers, which helps in evaluating the parameters of the flap in refractive surgery.

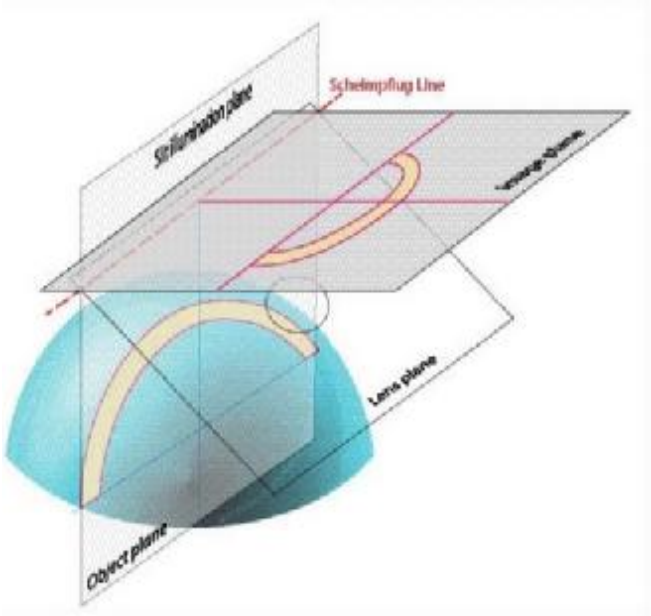
Scheimplug image[1] :

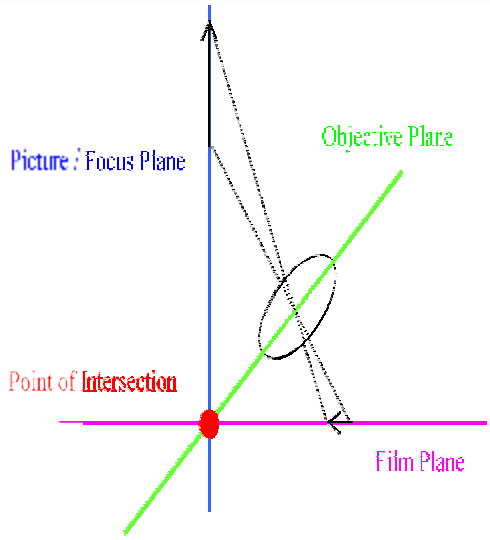


Scheimpflug image of the anterior segment

The principle of the schiemplug image depends on taking side images of light slices. A rotational blue slit light with fixation center is directed towards the cornea. The camera is laterally located and directed towards a rotational center, it captures all the media through which the light slit can penetrate and reach.

Principle:

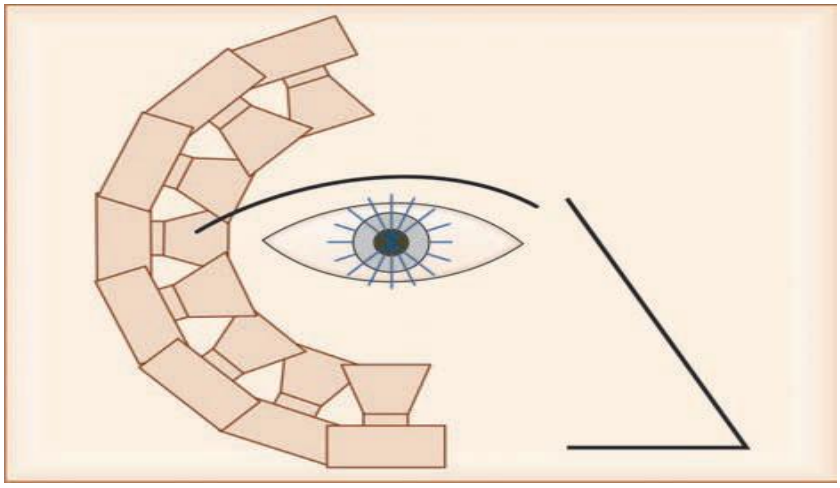




The scheimplug principle states that, 'if a lens is tilted such that the lens plane intersects the film plane, the plane of sharp focus must also pass through that same line'[27]. The Scheimpflug camera works on the optical principle of intersection. To get a higher depth of focus, three planes which includes the picture plane, objective plane and film plane

has to get each other in one line or one point of intersection so that images along the optical axis of the eye can be accessed to generate a real time Scheimpflug image of the anterior eye segment.

Scheimpflug Assessment[1]:



Captured section by the rotating camera of the Pentacam

The Patients were instructed to keep both eyes open and to fixate on a black target in the centre of a blue fixation beam. After perfect alignment was attained, the instrument automatically took 50 Scheimpflug images in 2 seconds. This system evaluates 500 measurement points from each slit image i.e., totally 25,000 true elevation points. The Measurement results were checked under a quality specification window only measurements with an OK reading were

accepted. If the comments were marked yellow or red (i.e., not OK) the examination was repeated. The following data were exported for further analysis. Pentacam provides elevation and curvature data in the form of colour coded maps. Flatter areas (above best fit sphere) are represented in 'cooler' colour (blue) and steeper areas (below the best fit sphere) shown in 'warmer' colour (red). For fitting best fit sphere (BFS) in a 9mm zone the proposed screening parameters are suggested.[16] The differences between the BFS and the corneal contour in the anterior elevation map are, Less than +12µm – consider as normal

1. +12µm to +15µm - suspicious of ectatic disease
2. More than +15µm - typically indicative of keratoconus.

Normal values for posterior elevation are approximately 5µm higher than those for anterior elevation. The Anterior Chamber Depth measured form the posterior corneal surfaces centrally, the anterior chamber depth at the thinnest point of the cornea. For local posterior elevation measurements, a toric ellipsoid was used as a reference body. The elevation maps from the device show the difference in height between the cornea and reference body, the value is positive when the measured point of the cornea is above the reference body and negative when it is below.

Posterior elevation data read as the maximum values above the toric ellipsoid surface in the central 5.0mm of the cornea, which in the keratoconus eyes shows thinnest point in the cornea. For posterior corneal elevation measurement, a BFS was used as reference surface. The Sphere that best fit the posterior corneal surface was automatically generated by the software. The BFS fits any direction of the corneal surface, rather than being set to fit only one direction such as apex or axial alignment. The posterior elevation maps, posterior the radial distance between the sphere and the posterior corneal surface, were then displayed with colour coded scales. On these maps posterior elevation was measured as the maximum value above the BFS in the central 5mm of the posterior cornea.

BFS

The BFS is important for three main reasons.

They are

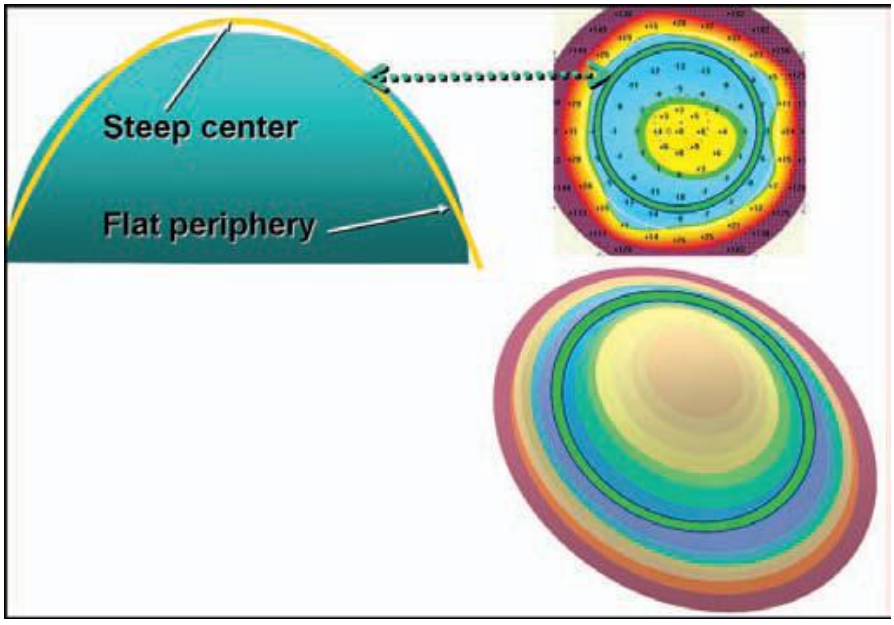
a) To see the shape of the cornea.

b) To search for an important risk factor that is the isolated island or the tongue like extension.

c) To locate the cone in Keratoconus.

ELEVATION MAPS

The Enhanced spherical Reference Body[1]

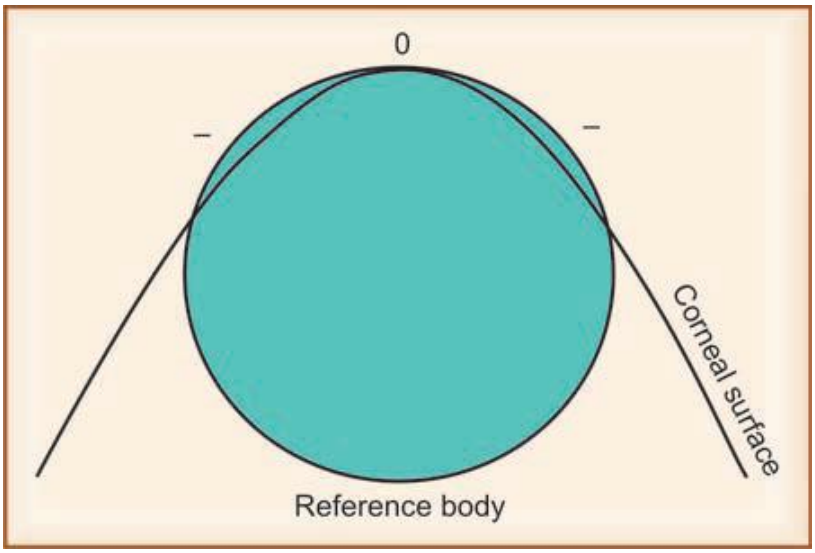


Corneal surface (yellow) has steep center and flat periphery in accordance to this particular reference body.

It helps in the early detection of keratoconus. With the BFS float mode, the computer adjusts a spherical body in a position that matches the total values of elevation and depressions in the external surface, depending on the mean corneal radius. If the computer is asked to delete an area of 4mm in diameter, where the center of the cone itself, the computer will adjust another spherical body. Notice the cone when

elevation is related to the modified red body rather than the yellow one. Obviously, the cone will be more clearly displayed.

Reference body[1]:



The reference body. It is the best body that fits the measured corneal surface according to its elevations and depressions.

For capturing each corneal surface the computer of the camera gives a reference body. The reference body of the corneal back surface may differ from the front surface of the same cornea. The reference surface is adjusted by the computer with the measured surface. The computer recognizes the points which are above the reference surface as elevations and are shown as positive values. It also recognizes the points

which are below the reference surface as depressions and are shown as negative values. These values are expressed in microns. The points between the measured surface and the reference surface are coincidence points which are shown as zero.

Types

- **Ellipsoid body-** According to the major and minor axes, ellipsoid body has an aspherical shape which is rotationally symmetrical. Its cross-section is coronally rounded and also helps in highlighting the real shape of the cornea.

- **Toric ellipsoid body-** According to the major and minor axes, ellipsoid body has an aspherical shape which is rotationally elliptical.

- **Spherical body-** It is better than the previous bodies in highlighting corneal irregularities since the normal cornea has a toric ellipsoid shape. It is well known that to recognize something, it should be matched with other different things. To show the details of abnormal cornea, it should be related to a spherical reference body.

Float Mode[1]:

The reference body can be adjusted with the examined surface of the cornea in various locations. If the reference body is adjusted in contact with the apex of the cornea it is called no float mode. Float mode is the distance between the two bodies should be equal in sum and minimum. The float mode is most commonly used as a standard to compare examinations carried out by various topographic systems. Unfortunately very early stages of keratoconus are difficult to recognize on the float shape due to distance optimized adjustment. That is because when a reference body is adjusted in contact with the corneal apex, any bulge near the apex will be relatively visible and visa versa, any small bulge might be lost among larger details when the reference body is adjusted away from the apex.

DISPLAY OF TOPOGRAPHIC DATA

The main page in pentacam consists of figures on the left and four maps on the right. The main four maps are,

a) Anterior sagittal curvature map

b) Anterior elevation map

c) Posterior elevation map

d) Pachymetry (thickness) Map

Corneal Thickness Map:

Depending on the elevation maps, the computer measures the corneal thickness at all points. Corneal thickness is indicated by the difference between the elevations of front and back surface of the cornea. The three important locations in these maps are

1) Thinnest location

2) Corneal apex

3) Pupil center

The main page displays the coordinates of each location, where the corneal apex is the original point. This map mainly helps in the following situations.

a) To diagnose corneal ecstatic diseases like keratoconus, pellucid marginal degeneration and iatrogenic ectasia.

b) Confirmation of corneal diseases which are diagnosed as Fuchs dystrophy and cornea guttata.

c) Observation of the previous diseases progression.

d) Taking right decisions in refractive surgery whether it was photorefractive surgery intracorneal ring implantation or corneal crosslinking.

e) To decide the exact amount of correction by LASIK surgery.

f) Planning for intracorneal rings in the management of kerataconus and pellucid marginal degeneration.

Difference Elevation Maps:

The map contains three colours only. When moving between the baseline elevation map and the exclusion map each colour corresponds to the amount of elevation change that occurs.

- The green colour represents a change in elevation of less than 6 microns on the corneal front surface and 8 microns on the corneal back surface and is typically within the range seen in normal eyes.
- The yellow colour represents a change in elevation between 6 to12 microns for the corneal front surface and 8 to 20 microns for the corneal back surface. These eyes fall in the suspicious zone.
- The red colour represents the elevation difference between the two maps are 12 microns anteriorly or 29 microns posteriorly and is typically seen in eyes with keratoconus.

Belin/ Ambrosio Ectasia Display[1]:

- Central 4 mm optical zone excluded and Enhanced best fit sphere is calculated
- Enhanced BFS resembles closely the normal peripheral cornea and exaggerates the conical protrusion or ectasia
- Ambrosio Relational thickness - (ART) = Thinnest point/ Pachymetery

TOPOGRAPHICAL CRITERIA

Inferior-superior Rabinovich law[1]:

The inferior-superior Rabinovich law reflects the inferior-superior asymmetry of the corneal surface. It is calculated by identifying the flat axis on the anterior sagittal curvature map.

Rowsky's rule of 2s[1]:

In occult keratoconus this rule states that,

- K-max steeper than 45 by >2D (>47D)
- K-max in one eye steeper than the fellow eye by >2D
- I-S ratio(Rabinovich law) >2D
- SRAX law- stands for Skewed Steepest Radial Axis Index. It is an index of the angulation between the two lobes of the bow-tie. SRAX >22 degrees is a risk factor.
- Peripheral thickness(at 5mm central circle) is more than the central thickness by >20 %

Progression and Diagnostic Evaluation:

Corneal topography is the most important in diagnostic and progression of keratoconus. The Rabinowitz diagnostic criteria for keratoconus screening are[28],

1) Keratometry value and central steepening of the cornea more than 47.2 Diopters.
2) Inferior versus superior corneal diopteric assymmetery >1.2
3) Sim-K astigmatism > 1.5 Diopters
4) Skewing of radial axis >21Degrees

KISA Percent incorporates the K and I-S values with measure, quantifying the regular and irregular astigmatism into one index.

KISA % = K× I-S ×AST ×SRAX×100

K Value –Steepening of Central Cornea

I-S Value – Inferior - superior Diopteric asymmetry

AST – Corneal astigmatism index

SRAX – Skewed radial axis index

This index is highly sensitive and specific in differentiating the normal from keratoconic corneas. A Value of greater than 100% is highly suggestive of keratoconus and the range from 60 to 100% represents keratoconus suspects.

The three most important criteria of progression during a period of less than one year are[1]:

- Increase in K-max ≥ 1 D
- Increase in topographical astigmatism ≥ 1 D
- Decrease in corneal thickness at the thinnest location ≥ 30µ.

KERATOCONUS INDICES

Progression Index:

Thickness location relationship can be introduced as an index called the progression index. The Normal value of the progression index is <1.1. The Progression index reflects the rapid change of thickness from the thinnest location to corneal periphery; the bigger the progression, the higher the index and vice versa. High index (>1.1) is usually encountered in Keratoconus and ecstatic corneal disorders.

Factors involved in screening corneal topography:

- Evaluate the range and magnitude of curvature that is present in the pattern, which is related to the severity of the keratoconus.
- Evaluate asymmetry or irregularity of the contour pattern.

Topographic differencial diagnosis of keratoconus:

Following are the most common cases showing irregularities,

- Use of contact lenses, most often with RGP lenses
- Postcorneal surgery
- Scars
- Peripheral ulcerative diseases
- Salzmann's nodular degeneration
- Tear film disturbance

Advantage of Pentacam over Orbscan[29]:

Slices taken by the Orbscan are vertical image slices that are separated from one another and have no common point, any movement of the eye occurring during the two seconds of the examination make it impossible to re-register and reconstruct the image. In the Pentacam the central part of each meridian is known and during the two seconds exploration the Pentacam software reconstructs a three dimensional image, assistive with a second camera that captures eye movements and

makes appropriate corrections. This is the most is important factor that makes Pentacam more precise than Orbscan.

Meanings of Abbreviations:

1) K_1 : Curvature power of the corneal flat meridian which is measured within the central 3mm circle and is expressed in dioptres.

2) K_2: Corneal curvature power of the steep meridian measured with in the central 3mm circle and is expressed in diopters.

3) Km: Corneal Mean Curvature power within the central 3mm and is expressed in diopters.

4) Rh: Horizontal Curvature radius of the central 3mm expressed in millimetres.

5) Rv: Vertical curvature radius of the central 3mm expressed in millimetres.

6) Rm: Mean curvature radius of the central 3mm radius expressed in millimetres.

7) Qs: Quality specification. It specifies the quality of the topographic capture and should be displayed “OK” otherwise

there is some missed information which was virtually produced by the computer and capture should preferably be repeated

8) Q-val: value of Q with in the central 6 mm as shown between two brackets. Any other central circle can be chosen through the program settings.

9) Astig: Amount of corneal astigmatism on the front cornea surface the amount of differentiation between the two curvature radii (K_2-K_1) with in the central 3 mm.

10) Axis: The axis of corneal astigmatism within the central 3mm.

11) Rmin: minimum radius of curvature expressed in millimetres.

12) Rper: Radius of corneal curvature in the peripheral 9 mm of the cornea expressed in millimetres.

Uses of the Pentacam:

1. The Most important use of the Pentacam is refractive surgery. It is indispensible tool for the evaluation of cornea in pre and post refractive surgery. One of the useful tool to identify the ectatic conditions using pentacam are corneal thickness spatial profile and corneal volume distribution. The Pentacam gives a quad map giving the anterior and posterior elevation of the cornea, a limbus to limbus corneal pachymetry and the anterior curvature map. Belin/ Ambrosio Enhanced Ectasia Display (BAD) are a display used to check the suitability of the eye for LASIK.
2. Pentacam used in the evaluation of cataract density and volume, which helps in preplanning of phacoemulsification parameters to be used so as to increase the efficacy and safety of the surgery.
3. Pentacam is useful in planning and screening Intacs for patients with keratoconus[26].
4. Pentacam is useful in the correction of astigmatism because of its corneal topographic and thickness maps. These maps are helpful to perform the limbal relaxing incision or astigmatic keratotomy either intra or post-operatively.

5. Pentacam provides a Zernike analysis of the cornea which helps in determining the appropriate customized IOL for specific patients.
6. Pentacam is used to evaluate the cataract location, density, thickness and consistency which helps in determining the three dimentional assessment of the eye for surgical planning.
7. Pentacam evaluates the anterior chamber depth, width and angle measurements. [26]The software provides a colour coded map of the anterior chamber depth both central and peripheral. Anterior chamber volume(ACV) was found to be a good screening tool for diagnosing the eyes with narrow angles with a cut off of $110mm^3$.

MANAGEMENT OF KERATOCONUS

Management of keratoconus includes optical correction, replacement technology additive technology and strengthening technology.

1. **Optical Correction:** It includes spectacles and contact lenses. Spectacles useful in early stages by correcting the refractive error, but not altering the shape of the cornea. Contact lenses also used in 90% of the patients. Early in the disease soft contact lenses of toric design in useful. However in advanced disease rigid gas permeable lenses which includes multicurve spherical based lenses, asperic lenses and bispheric lenses may be required. A hybrid lens has a rigid central portion for obtaining best optics and a soft hydrophilic peripheral skirt is also popular. The complications associated with contact lenses are corneal abrasion, apical scarring, hypoxia, neovascularisation and discomfort of the lens.

2. **Replacement technology:** This technology mainly involves corneal transplantation surgery in which diseased corneal layers are replaced by healthy tissue. It mainly includes lamellar keratoplasty

and penetrating keratoplasty which depends upon the depth of involvement and presence or absence of scarring.

Epikeratoplasty - It is a type of onlay lamellar keratoplasty in which the partial thickness donor cornea is placed on de-epithelised recipient cornea. It may be preferred over penetrating keratoplasty in selected cases like downs's syndrome because of its non invasive nature and reduced potential for the rejection of the graft.

Deep anterior lamellar keratoplasty (DALK) -It is a type of lamellar keratoplasty in which lamellar dissection is performed up to the descement's membrane and then the donor corneal button is sutured in its place. It reduces the incidence of endothelial rejection of the graft.

Automated lamellar therapeutic keratoplasty (ALTK) – In this procedure a microkeratome is used to excise the pathological part of the host cornea up to a particular depth and a healthy donor cornea, which is also cut using an automated microkeratome and an artificial chamber is sutured in its place.

Penetrating keratoplasty (PKP)– It is the procedure of choice for management of cases of keratoconus not adequately

rehabilitated by contact lenses. The success rate versus from 93%-96%. The indications for PKP includes contact failure, central scarring and poor acuity despite contact lenses. However a full thickness graft is associated with complications like graft rejection, post operative astigmatism and recurrence of keratoconus.

3. **Additive technology** – The additive technology for the treatment of keratoconus consists of the use of intrastromal corneal ring segments(ICRS) which are manufactured under two names-Intacs prescription inserts and Ferraria intrastromal corneal ring segments. Intrastromal corneal ring segments- Two thin arcs made up of PMMA are slid between the layers of the corneal stroma through incisions made in the corneal periphery. The segments flatten the peak of the one, thus reducing the amount of myopia and make patients more contact lens tolerant. The Potential complications include accidental penetration through the anterior chamber, infection, migration or extraction of segments.

4. **Strengthening technology**:

Corneal collagen cross-linking is a new approach to increase the mechanical and biochemical strength of the corneal tissue.

Corneal cross linkage (C3R):

Crosslinking of the cornea is an approach which increases the stability of the stromal tissue mechanically and biochemically. The idea of crosslinkage to treat Keratoconus was first proposed in Germany in the 1990s by a research group at Dresden Technical University mainly to delay the progression of Keratoconus. Thus collagen crosslinking helps to block the progression of Keratoconus temporarily mainly in the refractive phase. Crosslinking freezes stromal collagen, increasing the biomechanical stability of the cornea.

Collagen X-linking creates additional chemical bonds by means of photopolymerization in the anterior stroma. Riboflavin, when activated by ultraviolet A, creates free radicals which induce new chemical bonds.

REVIEW OF LITERATURE

1. **Michael W Belin et al.,** Newer imaging techniques like optical cross-sectioning, Scheimpflug photography OCT measures both anterior and posterior cornea. Posterior cornea seems to be earliest indicator of ectatic change. Among these Scheimpflug photography provides the most valuable information for diagnosing early ectatic change. Corneas with ectatic change shows more rapid thinning from the central periphery to the thinnest point. Comprehensive corneal analysis improves the refractive surgeon to screen patients for occult ectatic diseases.

2. **Illes Kovacs et al.,** Found that segmented analysis of the correlation between posterior elevation and central anterior chamber depth showed a better fit to data than linear regression and identified 40μm threshold for posterior elevation. Posterior elevation and minimum pachymetry seems to be useful parameter in corneal protrusion with keratoconic eyes.

3. **Susannah Quisling et al.,** Compared posterior elevation measurement above the best fit sphere and pachymetry in established keratoconus patients with pentacam and orbscan determines thinnest point with measureable difference in posterior elevation. This difference is important in screening patients for refractive surgery to avoid patients with early keratoconus.

4. **Kasturi bhattacharjee et al**., Found pentacam HR is very effective in detecting early keratoconus. For detecting anterior corneal elevation orbscan and pentacam are equally effective. To generate posterior corneal elevation above the best fitted sphere orbscan is greater than the pentacam thereby giving a false positive result. Since orbscan gives false positive results of posterior elevation, it is less effective than using pentacam.

5. **Rie ishii et al**., In keratoconus, measurement of posterior elevation using elevation based topography may improve keratoconus diagnosis accuracy. When combined with conventional curvature mapping

provides useful determination of the progressive stage of the keratoconus.

6. **Mihaltz et al**., Evaluated the alteration of keratometry, pachymetry, and elevation parameters of keratoconic and normal corneas using pentacam. Scheimpflug imaging found that all parameters are significantly different in keratoconic group with the normal control group.

7. **Pinero et al.,** Evaluated corneal volume pachymetry and correlation of the anterior and posterior corneal shape in sub clinical and clinical keratoconus they found progressively lower pachymetry readings in subclinical, early, and moderate keratoconus, however they did not find significant differences in these parameters between subclinical keratoconus eyes and normal eyes.

8. **Ciolino et al.** studied posterior corneal elevation changes following excimer treatment in 121 myopic eyes using Pentacam. They found there was no significant difference between the posterior displacement of LASIK and Photo Refractive Keratectomy (PRK) eyes. No LASIK eyes showed significant forward displacement[30].

9. **Quisling et al.** Compared the measurements of Pentacam and Orbscan IIz in patients with keratoconus. The Orbscan IIz BFS fixed to the apex was compared with Pentacam posterior BFS with removed float option. The average BFS radius and the average thinnest points were not significantly different between the two systems. But the posterior elevation was significantly different despite to similar to the radii of curvature. Pentacam images the cornea directly whereas Orbscan estimates only the central 3mm zone. They found that both machines shows the cones are most commonly located in the inferior temporal quadrant[31].

10. **Ambrosio et al.** Evaluate the normal and keratoconic eyes using Pentacam to determine the characteristics which helps to detective keratoconus. Pentacam shows the 3 dimensional model of corneal thickness, volume and spatial profile. Corneal thickness at the thinnest point was used to create spatial thickness profile and volume centered around the thinnest point. They found significant difference in all positions of the spatial thickness and profile and volume distributions, with lower values for each in keratoconic eyes. Keratoconic eyes were thinnest with less volume and a more abrupt

increase as one moved outward from the thinnest point of the cornea than normal eyes[32].

11. **Dubbelman et al.** Investigated the shape of anterior and posterior surface of the cornea relative to aging. They collected the Scheimpflug images of 114 eyes ranging from 18 to 65 years of age. A found that toricity of the posterior surface does not mirror the anterior surface astigmatism and also the vertical meridian has changed more than the horizontal meridian[33].

AIM & OBJECTIVES

AIM:

To evaluate the progression of Keratoconus using Pentacam

OBJECTIVES:

To assess the rate of change in corneal parameters using pentacam.

To assess the relationship between the change in corneal parameters and age.

MATERIALS AND METHODS

STUDY DESIGN:

Prospective observational study

STUDY SUBJECTS:

All diagnosed cases of Keratoconus

STUDY CENTRE:

Cornea clinic, Aravind Eye Hospital, Madurai.

STUDY PERIOD:

Period of recruitment- March 2013 to March 2014 Minimum follow up - Six Months.

INCLUSION CRITERIA:

- All diagnosed cases of keratoconus using retinoscopy, slit lamp and corneal topography (pentacam)
- People coming for follow up (upto 1 year).

EXCLUSION CRITERIA:

- Megalocornea and raised IOP
- Acute corneal hydrops
- Active infectious disease of cornea.
- People who has undergone C3R procedures.
- Chemical injuries of the eye and unhealing epithelial defect

CRITERIA FOR DIAGNOSIS OF KERATOCONUS ON PENTACAM:

- Corneal radius of curvature is equal to or > 47.2D
- Inferior superior diopteric asymmmetry in 4 mm zone is >1.5D
- Difference in pachymetry of upper and lower points in 4mm zone is >30 microns
- Difference of >10 microns between thinnest pachymetry and pachymetry at corneal apex
- Anterior elevation of > +15 microns
- Posterior elevation of > +20 microns

CRITERIA FOR KERATOCONUS PROGRESSION:

- Increase in Kmax more than or equal to 1 Dioptre
- Increase in astigmatism more than or equal to 1 dioptre
- Decrease in thinnest corneal thickness more than or equal to 30 microns.

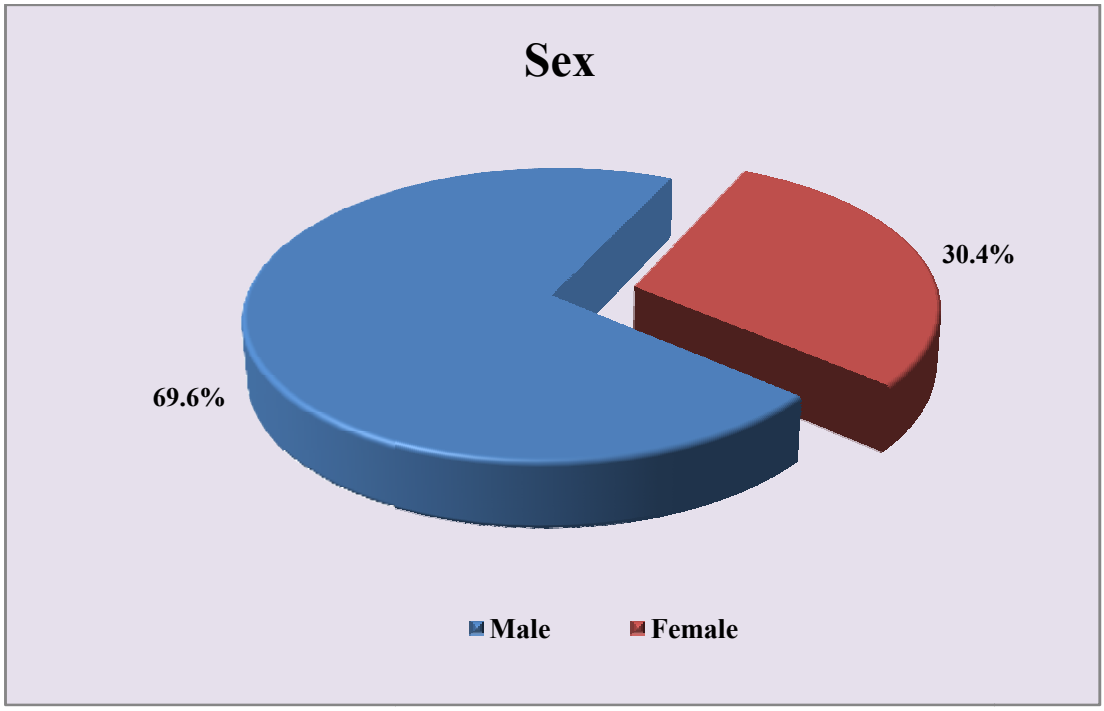
OBSERVATION AND RESULTS

AGE:

Mean (SD) of the age is 17.41(4.05) years and the range is 11 to 25 years

SEX:

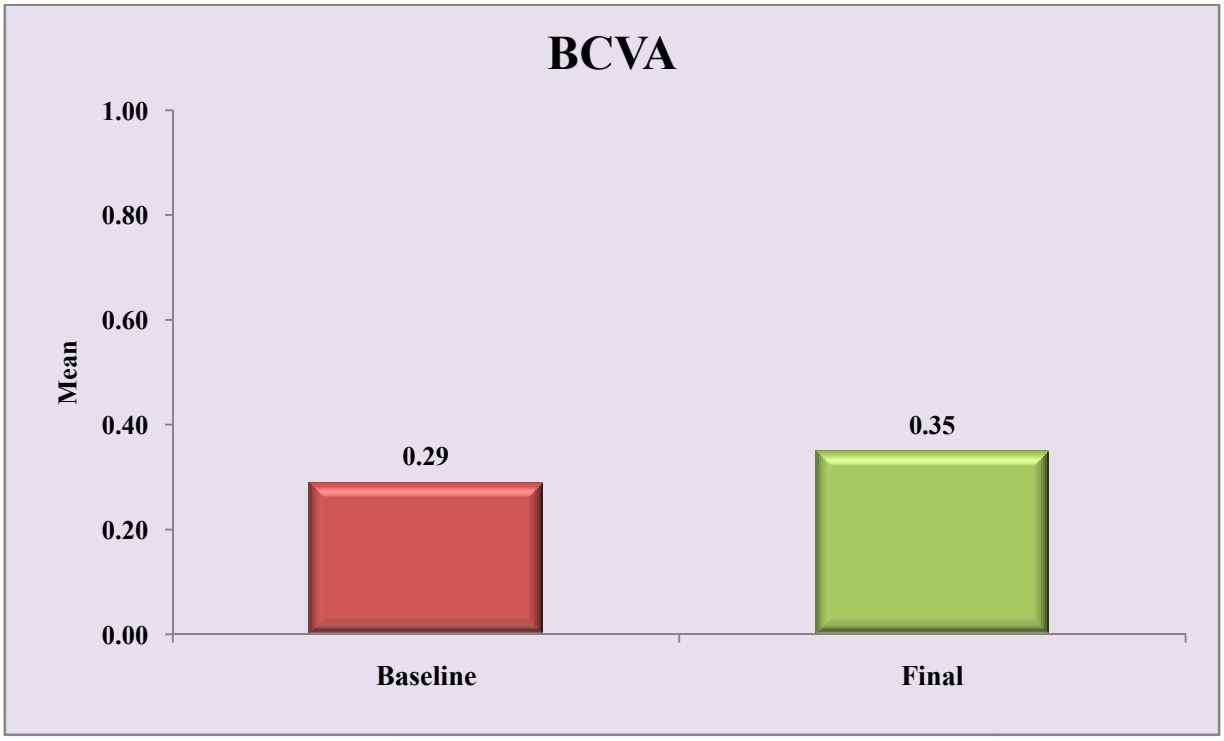
Sex	N	%
Male	39	69.6
Female	17	30.4
Total	56	100.0



BCVA:

BCVA	n	Median (Snellen's equivalent)	Mean(SD)	Min – Max	P-value*
Baseline	112	0.18(6/9)	0.29(0.30)	0 – 1.48	0.0001
Final	112	0.3(6/12)	0.35(0.31)	0 – 1.48	

*Wilcoxon signed ranksum test

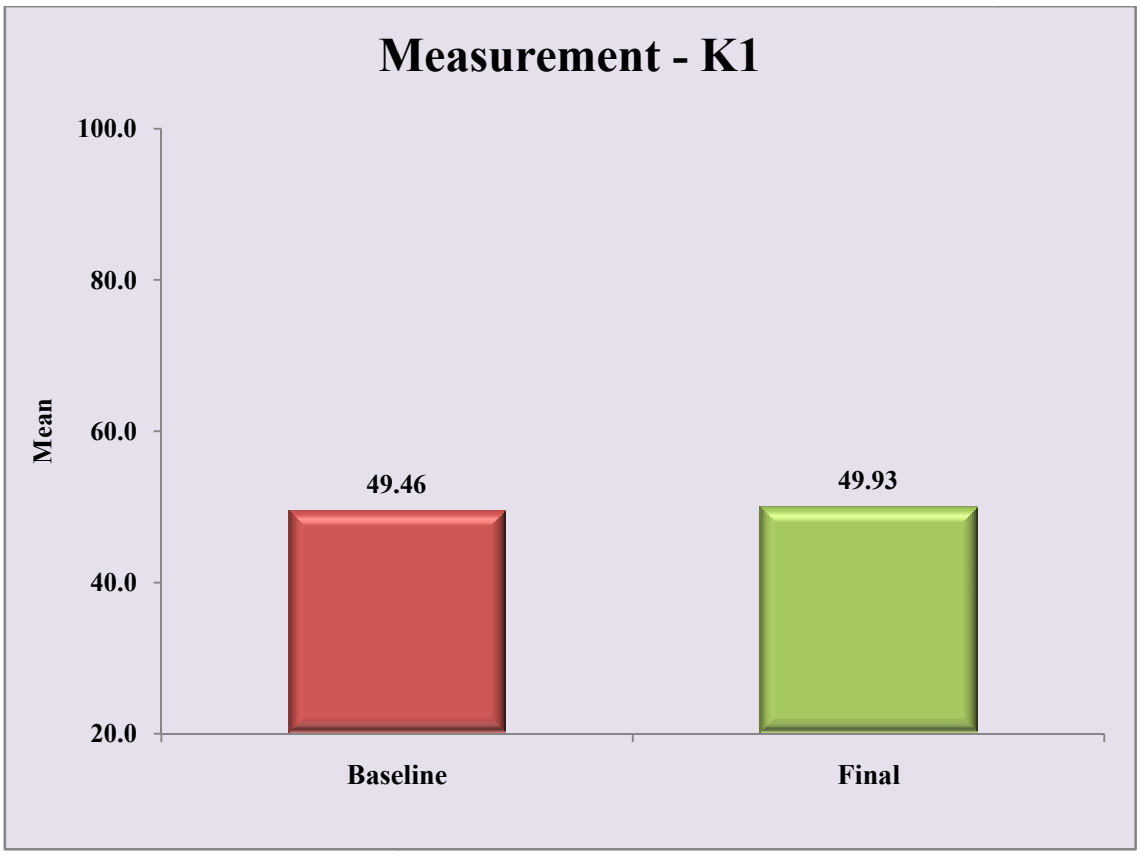


MEASUREMENT:

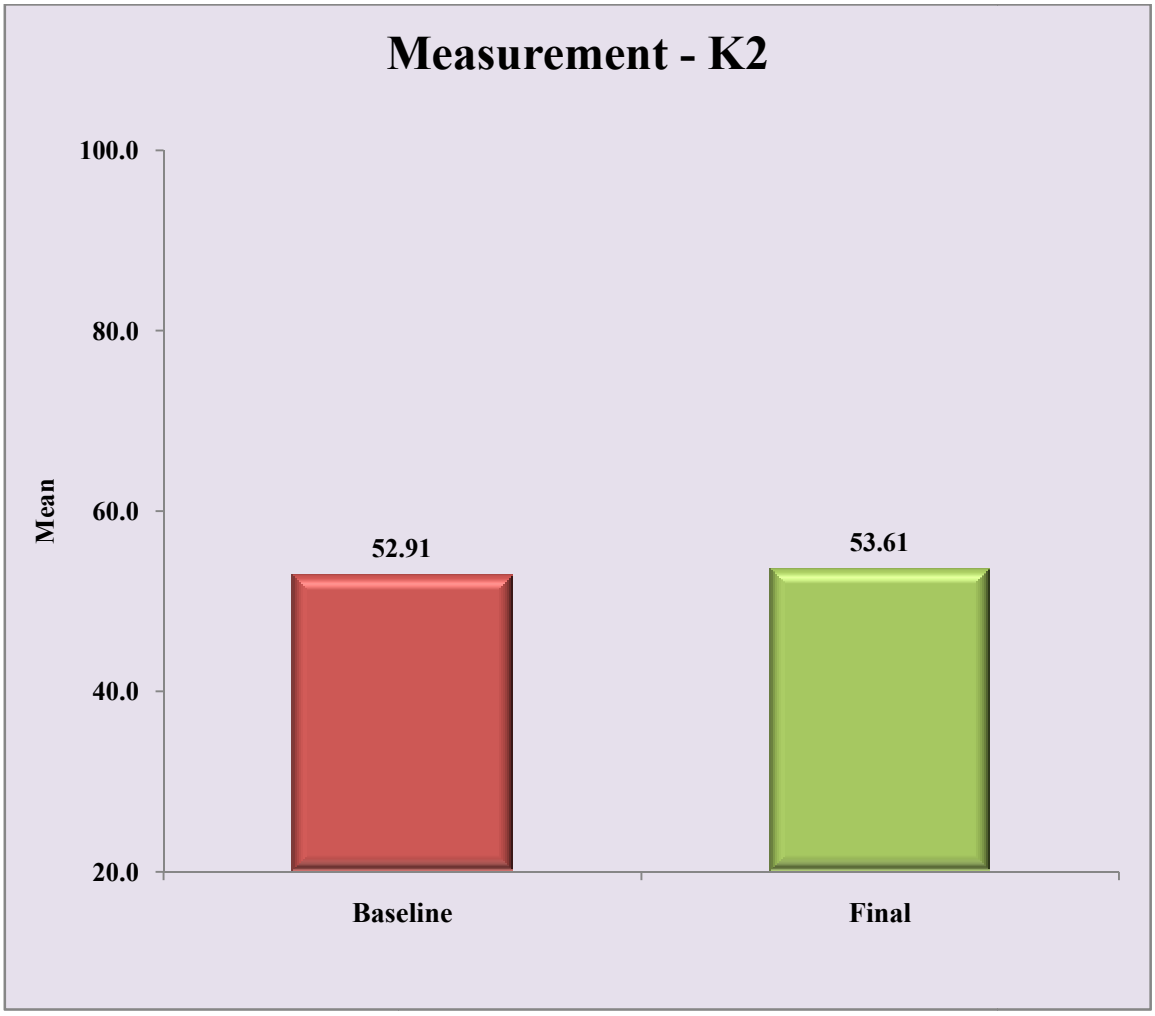
Measurement	Mean(SD)	Min – Max	P-value*
K1			
Baseline	49.46(5.48)	41.4 – 69.5	0.0033
Final	49.93(5.70)	41.6 – 67.6	
K2			
Baseline	52.91(6.47)	37.9 – 71.6	0.0015
Final	53.61(6.70)	37.8 – 73.5	
K-max			
Baseline	58.69(8.70)	44.7 – 82.5	0.0007
Final	59.40(8.62)	45.2 – 80.8	
Astigmatism			
Baseline	4.18(2.13)	0.5 – 8.8	0.821
Final	4.24(2.12)	0.5 – 10.1	
Thinnest corneal thickness			
Baseline	441.61(43.78)	315 – 539	<0.001
Final	433.63(49.62)	321 – 533	
Anterior elevation			
Baseline	30.19(14.81)	3 – 75	0.0053
Final	31.98(14.98)	2 – 74	
Posterior elevation			
Baseline	61.97(30.41)	3 – 178	0.3593
Final	63.12(32.94)	2 – 166	

*t-test

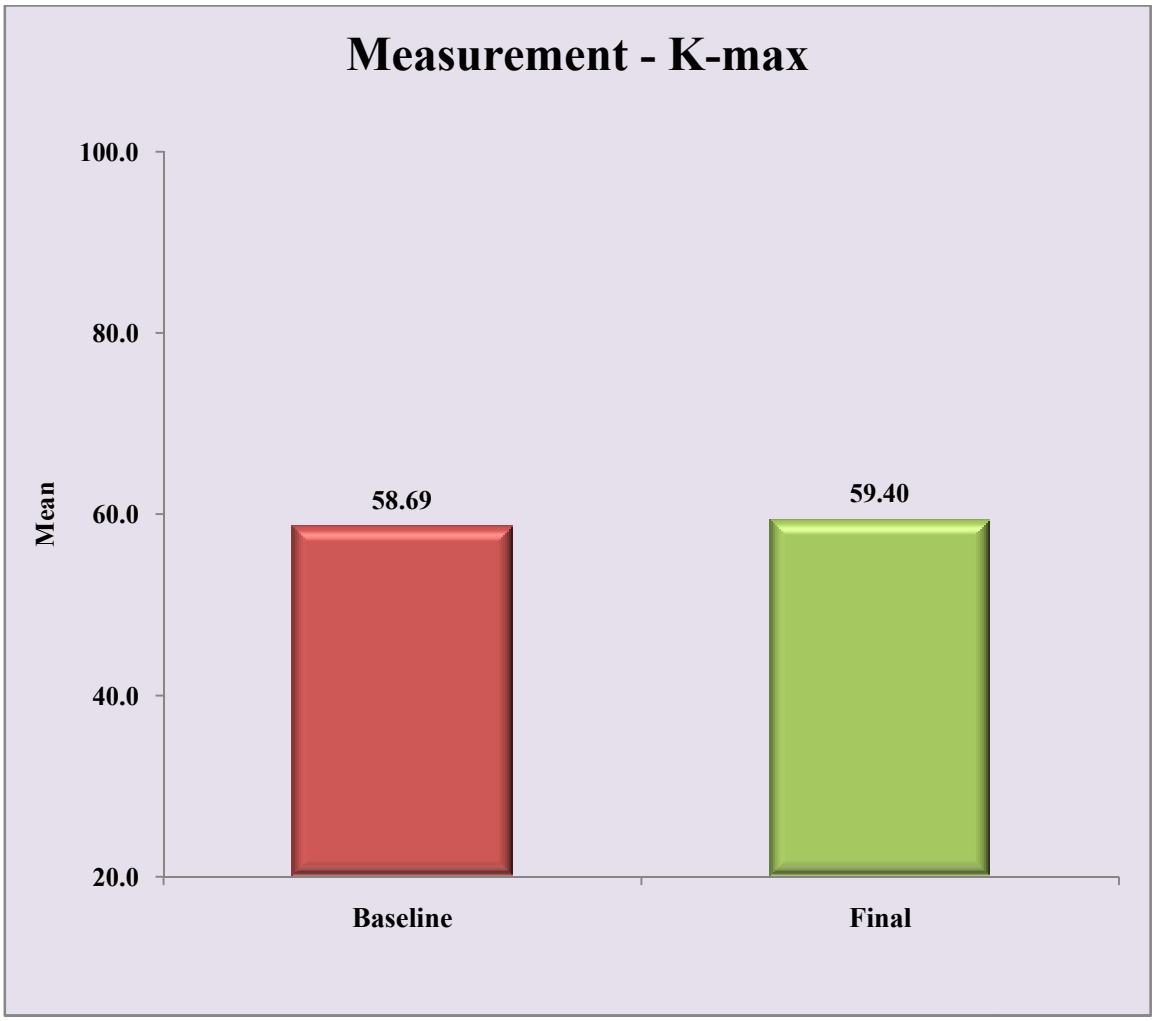
Measurement - K1	
Baseline	49.46
Final	49.93



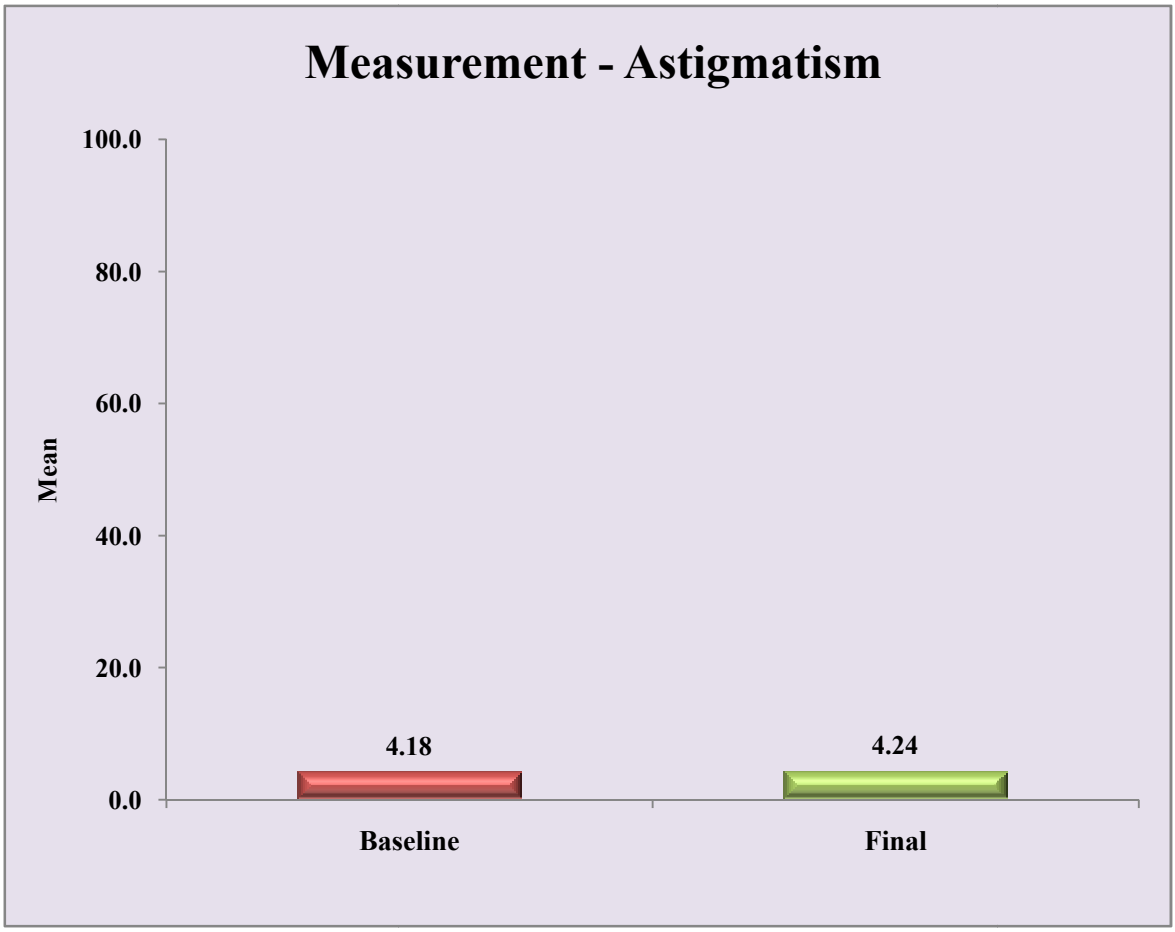
Measurement - K2	
Baseline	52.91
Final	53.61



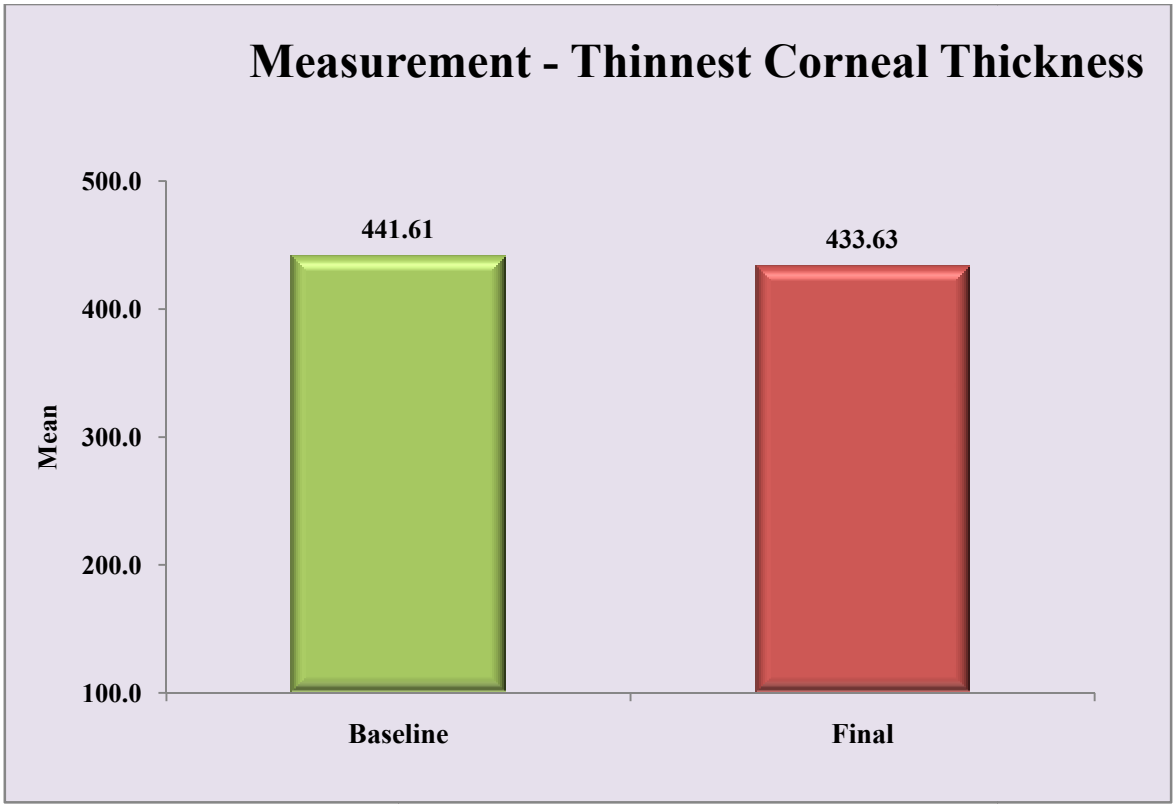
Measurement - K-max	
Baseline	58.69
Final	59.40



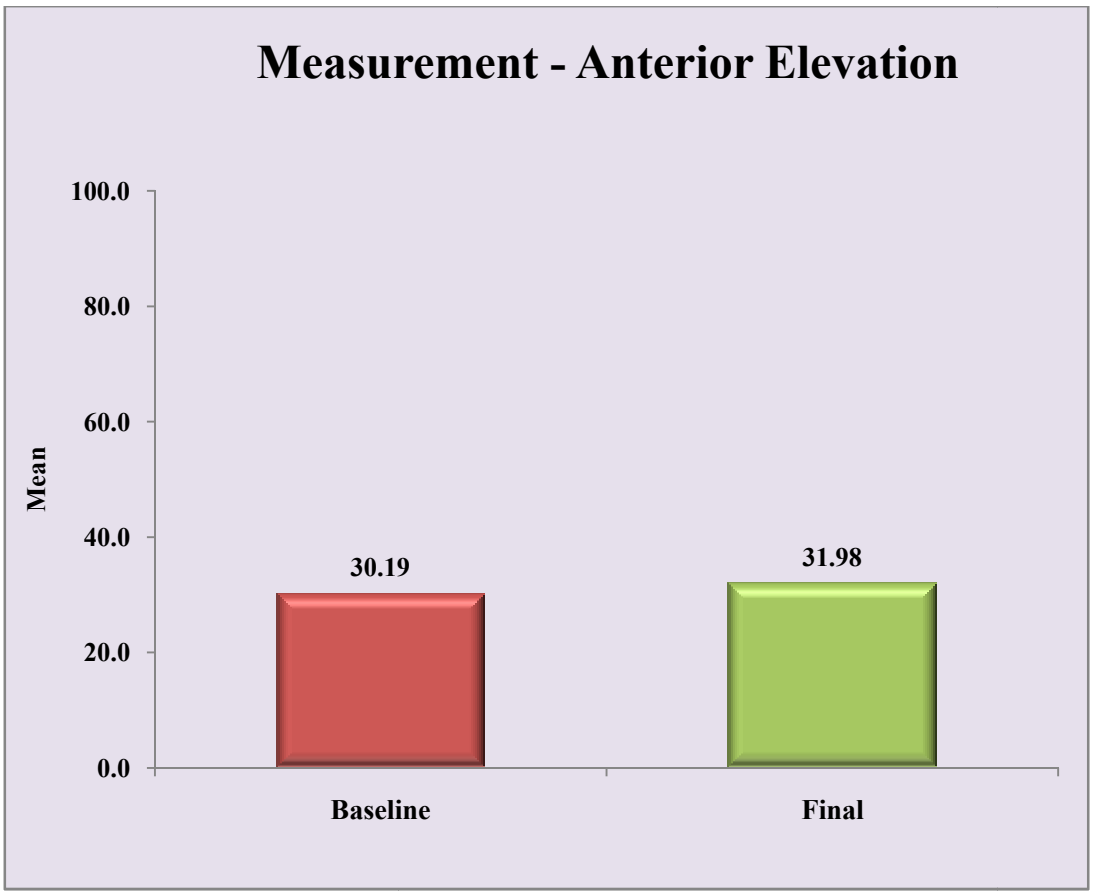
Measurement – Astigmatism	
Baseline	4.18
Final	4.24



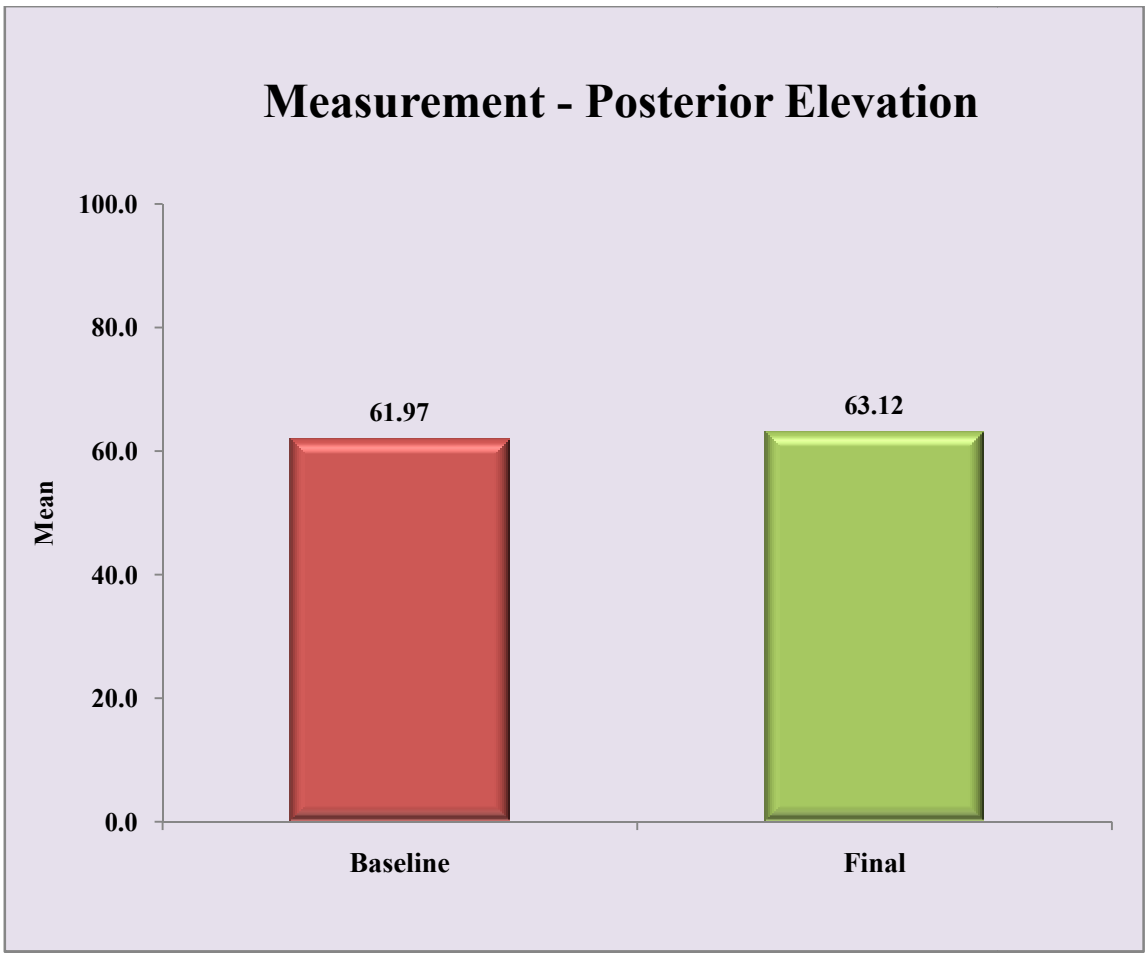
Measurement - Thinnest corneal thickness	
Baseline	441.61
Final	433.63



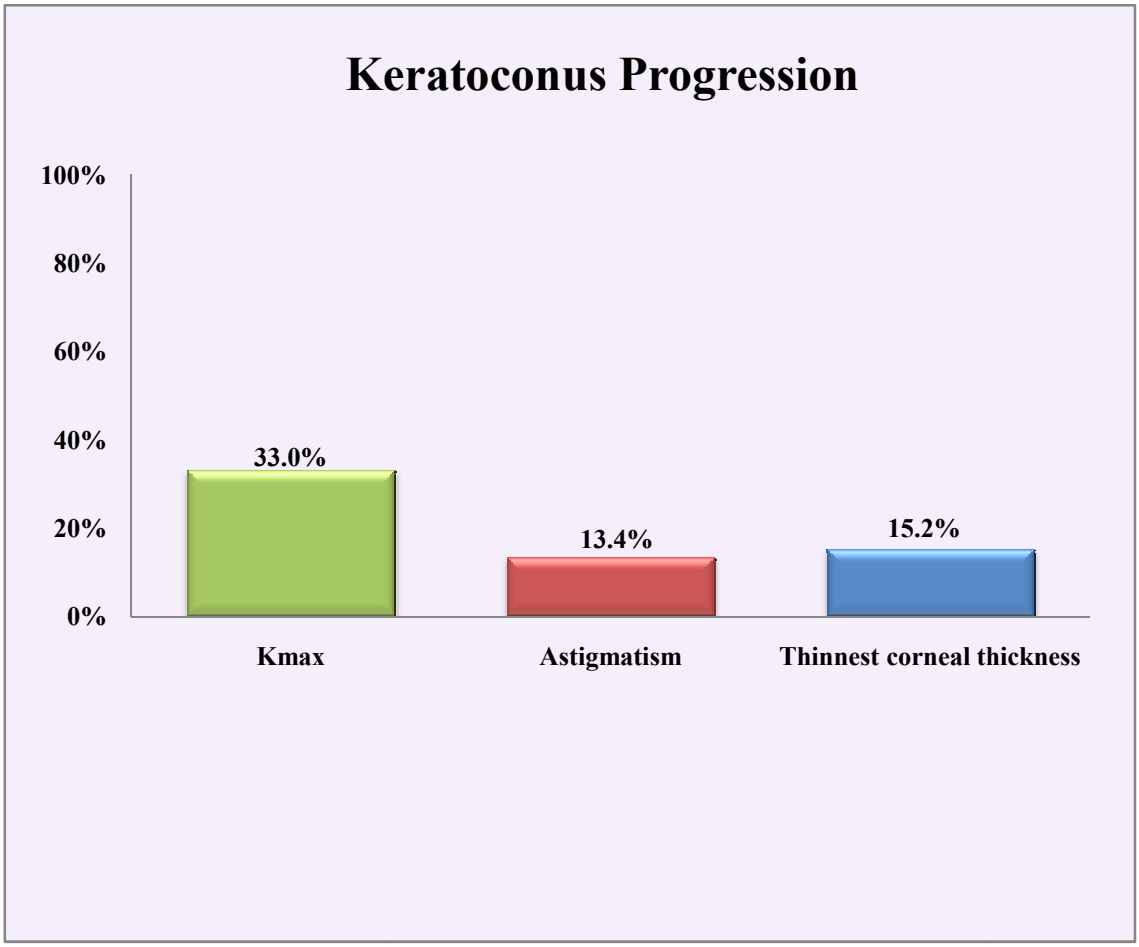
Measurement - Anterior elevation	
Baseline	30.19
Final	31.98



Measurement - Posterior elevation	
Baseline	61.97
Final	63.12



Keratoconus Progression	
Kmax	33.0%
Astigmatism	13.4%
Thinnest corneal thickness	15.2%



KERATOCONUS PROGRESSION

Keratoconus progression	n	%
Kmax more than or equal to 1D	37	33.0
Astigmatism more than or equal to 1D	15	13.4
Thinnest corneal thickness more than or equal to 30 microns	17	15.2
Overall progression (eyes)	52	46.4
Overall progression(patient)	34	60.7%
Unilateral progression(eyes)	16	-
Bilateral progression(eyes)	18	-

DISCUSSION

Keratoconus is a progressive non inflammatory disorder of cornea that usually manifests during adolescence. Kennedy et al, in their clinical and epidemiologic study of keratoconus reported keratoconus prevalence rate of 54.5 per 1,00,000 in the general population. Prevalence of keratoconus as reported by Rabinowitz is between 50 and 230 per 1,00,000 in the population. The incidence and prevalence could not be commented in our paper because the study was conducted only among the patients attending our hospital. The disease has an insidious onset and a variable severity and patients may not seek ophthalmic care for a long time. As the disease is asymmetric, one eye may be affected more than the other. Some patients are able to perform their routine activities with the vision in the better eye. This possibly explains the reason for loss of follow up of some patients at 6months to 1 year who were initially eligible for the study. Rabinowitz YS, in his study on Keratoconus has reported that keratoconus usually presents at puberty and remains progressive till the third and sometimes fourth decades of life. Sainai et al, in their study of keratoconus among Asian patients reported that about 50% of patients presented before 20 years of age whereas Wagner et al, in their Collaborative Longitudinal Evaluation of Keratoconus

(CLEK) Study reported only 4% presented before the age of 20 years. Tufts et al in a study of 2723 keratoconus patients reported mean age at diagnosis of 22.4 years for males and 23.3 years for females. Crews *et al*, in a retrospective study on keratoconus reported the mean age of patients with disease presenting to hospital as 28 years. Our study showed that the mean age is 17.41years (range is 11 to 25 years). The reported gender predilection may vary for keratoconus. Thomas CI et al in his study on the cornea and Nuel JP et al in his study on keratoconus reported that females slightly outnumbered males. Sainai et al, study on keratoconus among Asian eyes in India, reported female preponderance of the disease. Rabinowitz in a review of keratoconus in the year 1998 reported that there is no sex predilection in keratoconus. Kennedy et al in his study on clinical and epidemiologic study of keratoconus, a 48-years clinical trial of keratoconus found annual incidence rate to be more among males. However, this difference was not statistically significant. A study conducted by N Lim at the Western eye Hospital reported a increased incidence of disease in the males. Keratoconus is essentially a bilateral disease of cornea, although presentation may be grossly asymmetric. It may take a few years after the initial diagnosis of keratoconus in one eye for the condition to become apparent in his/her fellow eye.

Among the imaging modalities to see the progression of keratoconus, the new elevation based topography-Pentcam which has a rotating schiempflug camera offers a non-invasive method of assessing the anterior chamber of the eye. It requires only 2 seconds to generate an image of the anterior eye segment. It acquires 12,25 and 50 images in a single scan[26]. The image slices of the cornea taken by Pentacam maintains the central point (thinnest point) of each meridian and also the software can re-register the central point and eliminates the eye moment

Although topography was developed more than 20 years ago the means by which to determine the corneal true shape is still evolving and has proven more problematic the some more recent development such as wave front analysis. The analysis of both anterior and posterior corneal surface and the corneal pachymetry distribution appears to have significantly enhanced the clinicians ability to identify the eyes at risk. Posterior elevation changes have been possibly one of the earliest change in keratoconus because placido system cannot measured the posterior surface and other elevation system were notoriously inaccurate in measuring the subtle changes to the posterior corneal curvature. The

combination of anterior elevation, posterior elevation and pachymetric distribution has greatly aided the diagnosis of early keratoconus.

Belin /Ambrosio enhanced ectasia display shows combined elevation based and pachymetric corneal evaluation which provides the clinician a global view of the structure of the cornea and to effectively screen the patients from ectatic disease. So accurate detection of keratoconus and its progression is important because condition is a direct contraindication for refractive surgery. Patients with keratoconus have abnormal collagen in addition to thin cornea. so this thin cornea do not have adequate tissue for ablative laser refractive procedure.

The Belin / Ambrosio Enhanced ectasia display was the first comprehensive refractive surgical screening tool to be fully elevation based. The goal of the software is to assist the refractive surgeon in identifying those patients who may be at risk for post-operative ectasia and/or to assist in the identification of early or subclinical keratoconus.

CONCLUSION

Our study was a prospective observational study undertaken to evaluate the progression of keratoconus using pentacam. The main objectives is to access the rate of change in corneal parameters using pentacam and to access the relationship between the change the corneal parameters with age.

In this study, the mean age of presentation was 17.41 (SD 4.05) years. Male preponderance of this disease was found, 69.6% of males were affected and 30.4% of females were affected. Bilateral disease was found to be more common than unilateral (based on keratometry and pentacam). The final best corrected visual acuity (BCVA) of 112 eyes (SD 0.35) was found to be significantly decreased compared to the baseline (SD 0.29) which was statistically significant (P-value 0.0001) by Wilcoxon signed ranksum test. The final keratometry value K1 (SD 5.70) and K2 (SD 6.70) was significantly increased compared to the baseline K1(SD 5.48) and K2 (SD 6.47) which was statistically significant. The final K-max value (SD 8.62) was significantly increased compared to the baseline K-max (SD 8.70) which was statistically significant (P-value 0.0007). The final astigmatism value (SD 2.12) was significantly increased compared to the baseline astigmatism (SD 2.13) was not

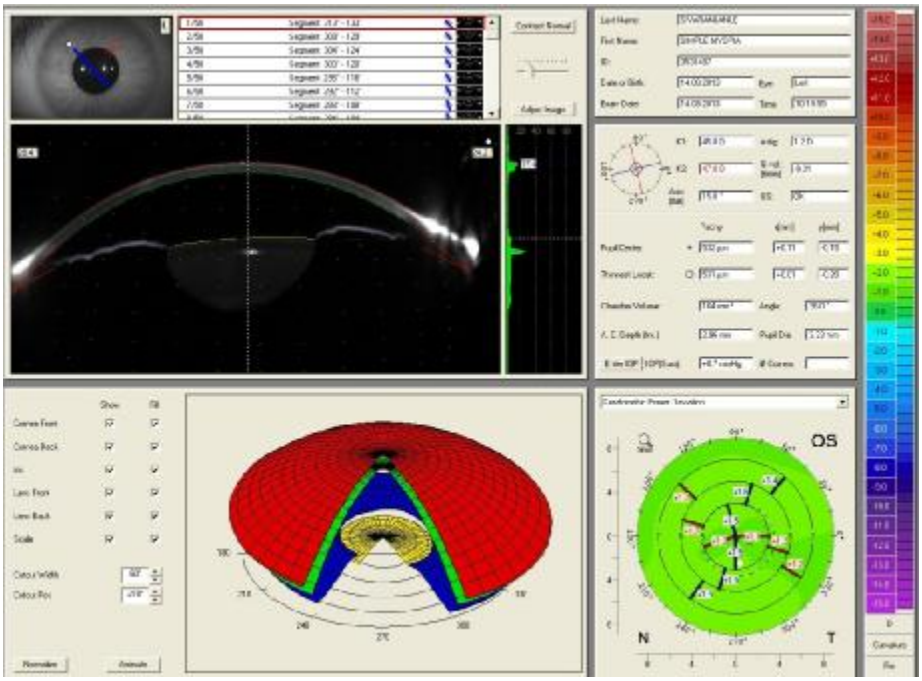
statistically significant (P-value 0.821). The final thinnest corneal thickness value (SD 49.62) was significantly decreased compared to the baseline thinnest corneal thickness (SD 43.78) was statistically significant (P-value <0.001). The final anterior elevation value (SD 14.98) was significantly increased compared to the baseline anterior elevation (SD 14.81) was statistically significant (P-value 0.0053). The final posterior elevation value (SD 32.94) was significantly increased compared to the baseline posterior elevation (SD 30.41) was statistically not significant (P-value 0.3593).

All the above parameters are statistically significant except for corneal astigmatism and posterior elevation. Our study includes only the patients who turned for follow up from the base line visit. Many of the patients has lost for follow up.

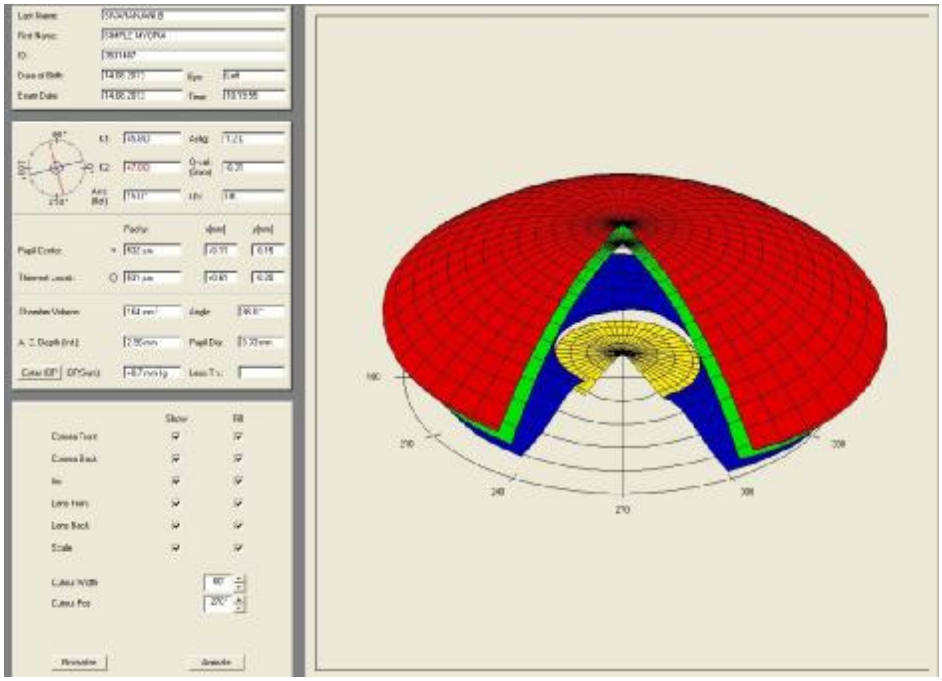
Out of 56 patients, 34 patients have progression which includes 18 patients have bilateral progression and 16 patients have unilateral progression according to our keratoconus progression criteria for pentacam. Remaining 22 patients who do not have significant progression according to our progression criteria has given distance best corrected visual acuity in the form of glasses and contact lenses. The patients those who showed keratoconus progression with eligible selective criteria has

advised for corneal collagen cross linking with Riboflavin (Isotonic/ Hypotonic C3R) procedure.

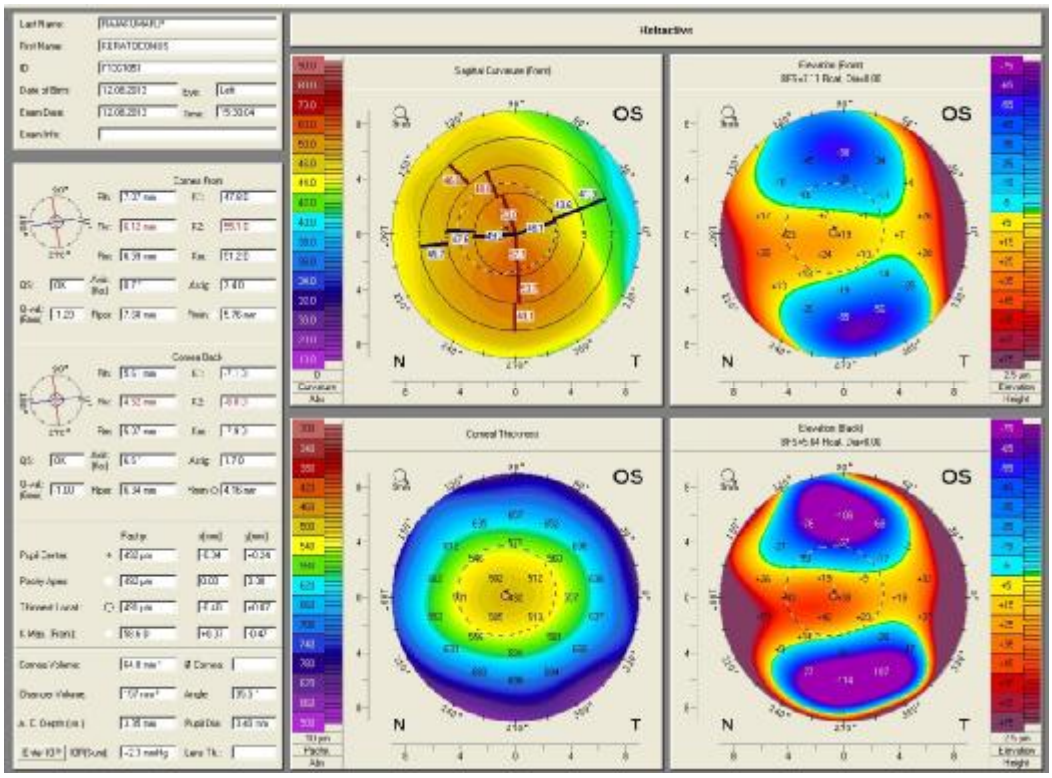
SCHEIMPFLUG IMAGE OVERVIEW



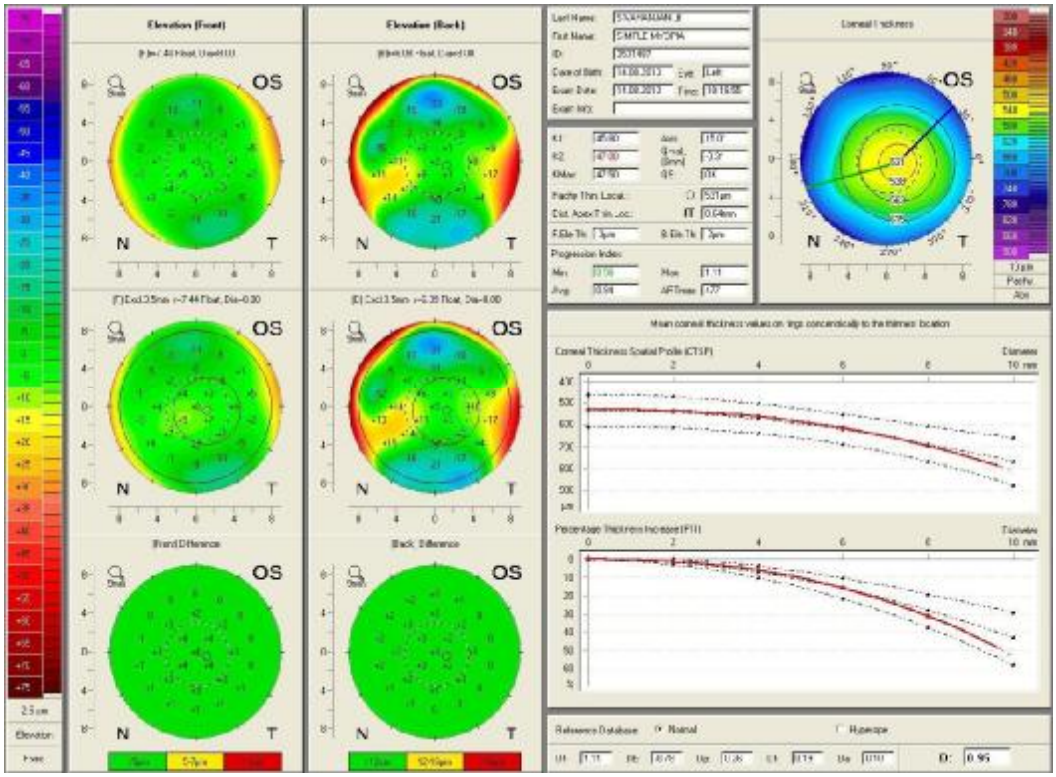
VIRTUAL IMAGE OF PENTACAM



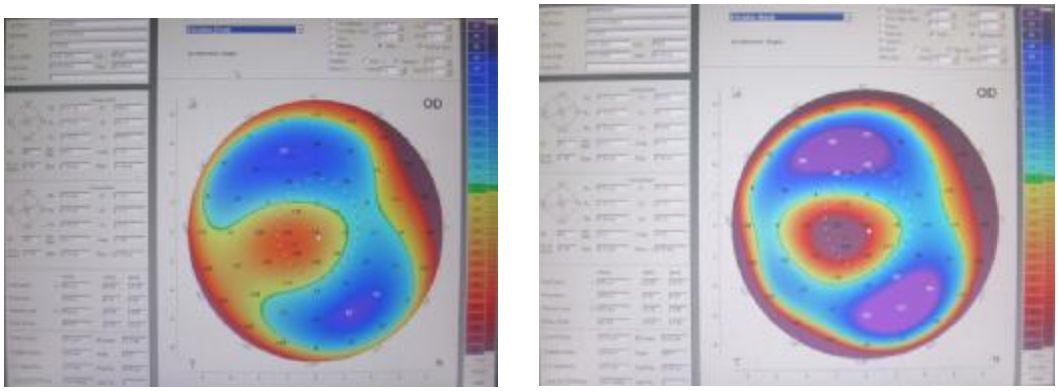
PENTACAM IMAGE OF KERATOCONUS



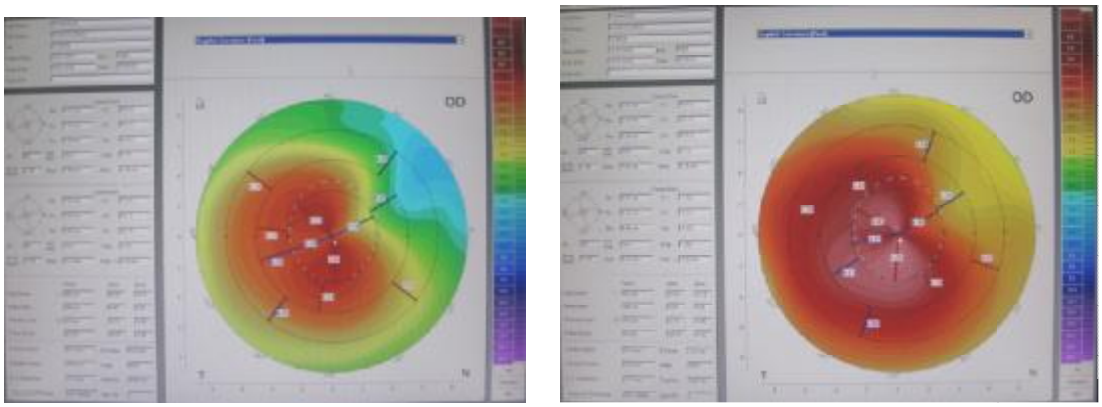
BELIN/AMBROSIO ENHANCED ECTASIA



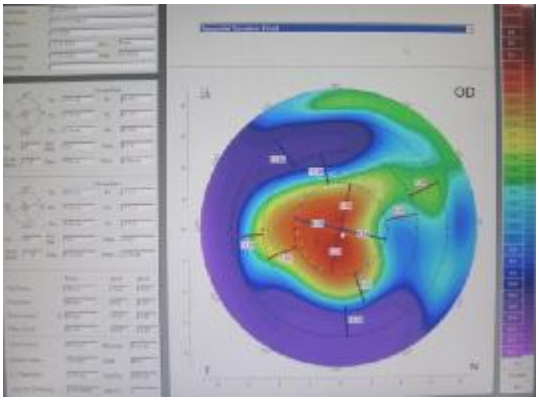
ELEVATION MAP SHOWING FRONT & BACK SURFACE OF CORNEA

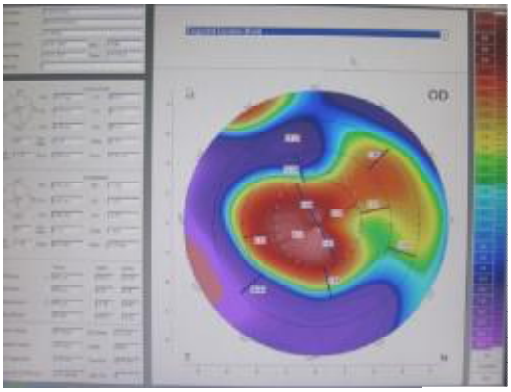


SAGITTAL CURVATURE SHOWING FRONT & BACK SURFACE OF CORNEA

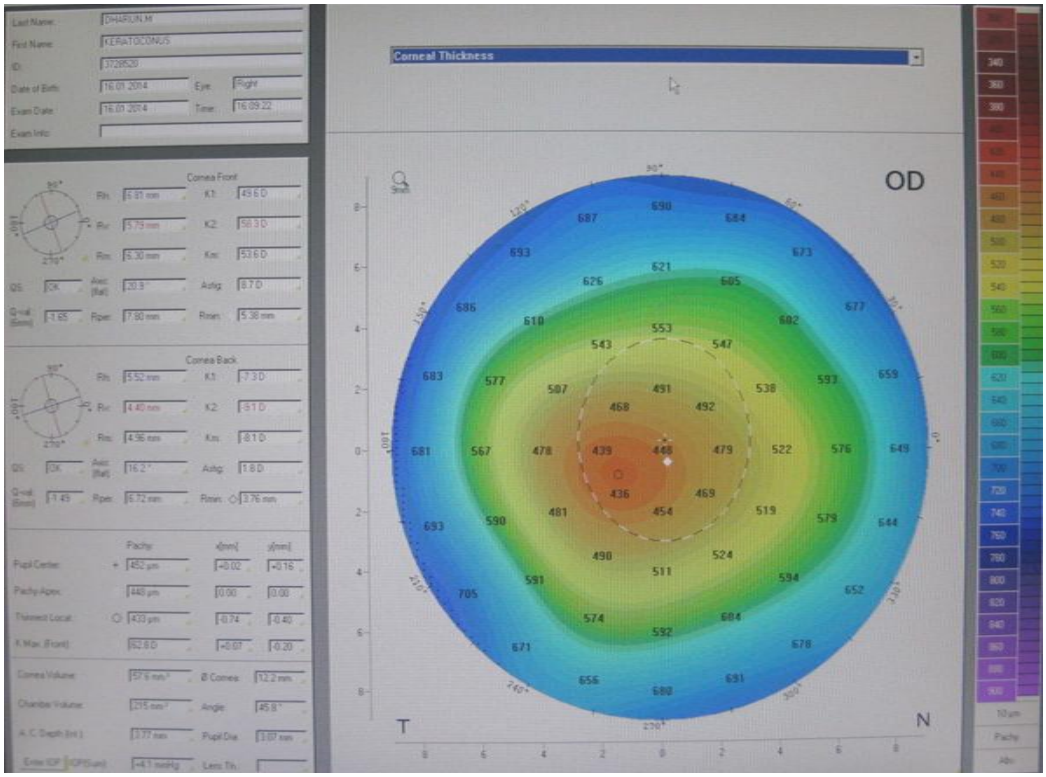


TANGENTIAL CURVATURE SHOWING FRONT & BACK SURFACE OF CORNEA





CORNEAL THICKNESS MAP



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PROFORMA

1. Name:
2. MR Number:
3. Age:
4. Gender : ☐

   1. Male 2. Female

5. Laterality: ☐

   1. RE 2. LE 3. BE

6. Best Corrected visual acuity (BCVA) with glasses

   RE..... LE.....

Pentacam Data: (visit 1)

Keratometry Reading K1 (D) K2(D)

K Max (D)

Astigmatism (D)

Thinnest location Corneal thickness (µm)

Anterior elevation at thinnest location

Posterior elevation at thinnest location

FOLLOW UP AT 6 MONTHS TO 1 YEAR

Best Corrected visual acuity (BCVA) with glasses

RE..... LE.....

Pentacam Data: (visit 2)

Keratometry Reading K1 (D) K2(D)

K Max (D)

Astigmatism (D)

Thinnest location Corneal thickness (μm)

Anterior elevation at thinnest location

Posterior elevation at thinnest location

ABBREVATIONS

BCVA	-	Best Corrected Visual Acuity
BFS	-	Best Fit sphere
D	-	Dioptre
K	-	Keratometry
mm	-	Millimetre
LASIK	-	Laser Assisted In situ Keratomileusis
PRK	-	Photorefractive Keratectomy
OCT	-	Optical Coherence Tomography
HR	-	High Resolution
SAI	-	Surface asymmetry index
SimK	-	Simulated keratometry
SRI	-	Surface regularity index
I-SV	-	Inferior-superior value

MASTER CHART

Sno	MRNO	Name	Age	Gender	Study Eye	BCVA	K1	K2	Kmax	Astig	Thin-loc corneal thickness	Ant-elevation	Post-levation	BCVA -Last	K1-last	K2-last	Kmax-last	Astig-last	Thin-loc corneal thickness-last	Ant-elevation-last	Post-elevation-last
1	3667542	DEEPIKA.S			LE	6/12	54.7	58.6	72.7	3.9	402	45	72	6/18p	55.7	58.9	72.5	2.8	379	54	85
1	3667542	DEEPIKA.S	25	Female	RE	6/18	53.9	59.6	71.4	5.7	384	44	74	6/18p	54.1	59	71.5	4.9	369	49	93
2	3657119	MD SHARIFUL HAS			LE	6/6	50.2	46.9	57.9	3.4	423	41	79	6/12	50.7	52.3	63.7	1.6	436	42	74
2	3657119	MD SHARIFUL HAS	18	Male	RE	6/6	50.9	53.8	63.8	3	413	36	69	6/12	51.1	54.8	64.1	3.6	413	42	83
3	3529281	SUNDARAKANNAN			LE	6/12P	52.9	59.9	69.4	7	409	53	72	6/12p	51.5	58.9	69.7	8.6	381	51	80
3	3529281	SUNDARAKANNAN	19	Male	RE	6/6	44.1	44.6	45.2	0.5	471	3	3	6/6	44	44.5	45.2	0.5	471	2	2
4	3588546	SUHANA.V.B			LE	6/9	43	45.5	48.8	2.5	475	21	57	6/9p	42.5	45.4	50.7	2.8	455	35	55
4	3588546	SUHANA.V.B	23	Female	RE	6/6P	43.9	45.4	47.1	1.6	492	10	33	6/9p	43.5	46	48.1	2.5	479	19	37
5	3560178	ATHUL AHMED			LE	6/36	48.3	50.8	60.5	2.5	426	42	73	6/36p	57	62.3	68.2	4.6	409	52	95
5	3560178	ATHUL AHMED	17	Male	RE	6/36	50.1	57.5	66.6	7.4	419	41	72	6/36p	61.1	67.8	72.9	6.3	391	55	130
6	3550303	MUNEER.V.V.K			LE	6/18	49.3	53	63.3	3.7	440	58	112	6/36	49.7	53.4	63	3.7	462	48	89
6	3550303	MUNEER.V.V.K	25	Male	RE	6/9	44.2	47.7	55.2	3.5	500	19	79	6/9	44	48.5	56.2	4.5	499	31	74

7	3549532	CHETHAN KRISHNAN			LE	6/12	49.2	55.6	58.6	6.4	450	28	63	6/12	49.1	54.8	57	5.7	452	49	49
7	3549532	CHETHAN KRISHNAN	18	Male	RE	2/60	62.8	71.6	77.8	8.8	355	48	147	5/60	63	71	76.5	8.1	349	50	153
8	3490382	RAVENDRABABU			LE	6/9P	50.6	56.6	58.9	5.4	410	27	50	6/9p	52.2	55.7	57	3.5	372	21	53
8	3490382	RAVENDRABABU	21	Male	RE	6/24	54.8	58.8	60.6	4	353	21	73	6/24	57.3	61	64.9	3.7	362	17	59
9	3581855	SHATHRUGHNA CH.			LE	6/6P	47.8	51	53.3	3.2	418	18	37	6/6p	48.3	51.3	53.9	3	417	16	33
9	3581855	SHATHRUGHNA CH.	20	Male	RE	6/6	45.8	47.3	48.4	1.6	446	6	21	6/6	45.6	47.6	48.5	1.9	444	6	17
10	3661626	KANNAN.S			LE	6/9	43.2	49.9	56.5	6.8	421	36	57	6/9	43.4	50.2	56.8	6.9	408	39	55
10	3661626	KANNAN.S	19	Male	RE	6/6	41.9	43.7	46	1.8	456	10	26	6/6	42.1	43.6	45.7	1.4	449	8	35
11	3576067	BAVANI.P			LE	6/6P	51.2	53	56.9	1.8	439	21	44	6/12	51	53.1	56.4	2.1	431	19	39
11	3576067	BAVANI.P	17	Female	RE	6/6P	48.6	51.7	53.9	3.1	449	14	27	6/6p	48.3	51.7	53.5	3.4	438	14	26
12	3600681	SHEIK MD SHAFI			LE	6/24	55.5	56.6	68.1	1.1	442	40	80	6/12	59.1	56.8	68	2.3	433	54	103
12	3600681	SHEIK MD SHAFI	12	Male	RE	6/24	59.5	65.1	72.6	5.7	436	62	128	6/18	62.2	66.3	74.9	4.1	397	62	135
13	3392243	ARUN BRITTO.A			LE	2/60	57.6	60.1	62.7	2.5	337	35	105	2/60	57.4	61.1	62.3	3.6	349	28	108
13	3392243	ARUN BRITTO.A	14	Male	RE	6/6	42.5	44	44.7	1.6	501	7	105	6/6	42.7	44.2	45.6	1.5	506	6	17
14	3378559	ASHIF KHAN.H			LE	6/9	41.9	43.7	46	1.1	410	12	80	6/9	49.1	53.6	57.2	4.5	404	42	65
14	3378559	ASHIF KHAN.H	17	Male	RE	6/9	58.6	64.5	78.6	5.9	377	72	105	6/24	61.4	65.4	79.1	4	380	55	93
15	3609008	MANJULA			LE	6/9	48.8	56.1	58.6	7.3	441	17	46	6/9p	48.6	56	57.5	7.3	438	37	41
15	3609008	MANJULA	15	Female	RE	6/12	52.2	57	61.9	4.9	439	26	60	6/12p	52.3	56.6	60.8	4.2	436	27	63

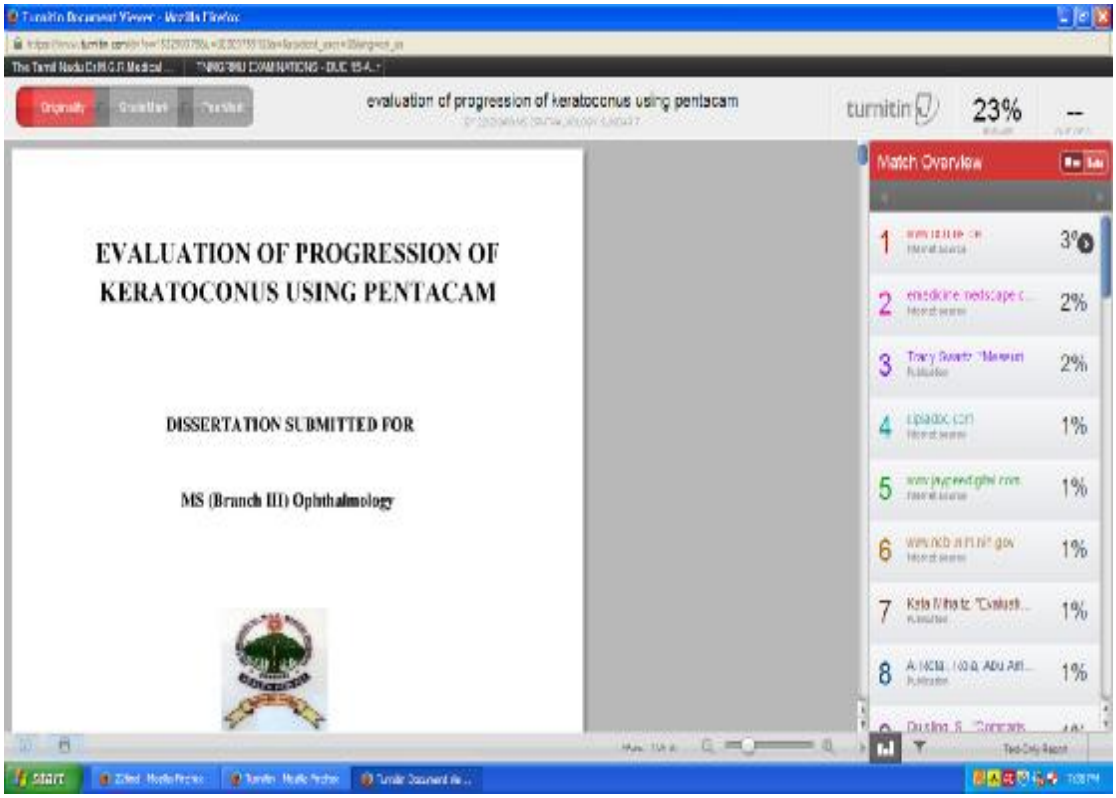
16	3613899	NAVALADI.S			LE	6/9	45.2	50.9	56.4	5.7	456	26	57	6/18	45.2	50.9	56.2	5.7	460	25	54
16	3613899	NAVALADI.S	17	Male	RE	6/6	44.1	45.9	47.8	1.8	485	10	24	6/6	44.2	45.8	48	1.6	494	10	28
17	3614763	RAJKUMAR.RM			LE	6/18	46.2	48	46.8	5.7	500	12	36	6/18	44.2	45.8	48	1.6	494	10	28
17	3614763	RAJKUMAR.RM	21	Male	RE	6/6	44.3	51.4	57.5	7.1	446	32	57	6/6	44.5	51.4	57.6	6.9	456	33	62
18	3578245	ARAVIND.P			LE	6/6p	46.4	49.3	53.6	2.9	431	17	36	6/6z	46.9	50.3	55.3	3.3	428	19	39
18	3578245	ARAVIND.P	17	Male	RE	6/12p	50.1	55.4	62.8	5.4	403	28	49	6/24	50.9	56	62.9	5	408	28	50
19	3169653	MD ASLAM.R			LE	6/24	47.2	50.4	56.4	3.2	432	28	49	6/24p	48.7	52.7	60.5	4	416	37	64
19	3169653	MD ASLAM.R	13	Male	RE	6/24	54.9	60.1	71.3	5.2	373	56	96	6/24p	56.3	58.8	71	2.5	376	49	78
20	3388757	KAVYA.N			LE	6/9	51.9	56.6	64.1	4.7	401	35	82	6/9p	51.2	57.2	63.5	6	347	35	97
20	3388757	KAVYA.N	15	Female	RE	6/18	61.5	68.7	71.4	7.2	315	35	156	6/24	58.3	64.4	68.9	6.1	331	36	158
21	3589299	SANTHOSH.P			LE	6/18	52.6	57.7	64.6	5.1	434	40	80	6/24	53.7	58.9	66.3	5.2	421	48	74
21	3589299	SANTHOSH.P	11	Male	RE	6/18	49.4	55.4	62.3	6	444	32	72	6/24	51.2	55.2	61.7	3.9	464	29	54
22	3597969	AKASH.T			LE	6/18p	51.6	58.5	71.6	6.9	396	55	89	6/24p	52.2	58.6	72	6.4	387	55	95
22	3597969	AKASH.T	15	Male	RE	6/6	42.4	45.3	49.8	2.9	460	15	48	6/6	42.1	45.5	50.4	3.4	459	25	52
23	3609008	MANJULA			LE	6/9	48.8	56.1	58.6	7.3	441	29	49	6/9p	48.6	56	57.5	7.3	438	37	55
23	3609008	MANJULA	15	Female	RE	6/9p	52.2	57	61.9	4.9	439	26	60	6/12	52.3	56.6	60.8	4.2	436	27	63
24	3612192	NARAYANAN. S			LE	6/18p	46.3	37.9	49.7	8.4	471	50	71	6/18p	45.4	37.8	50.4	7.6	476	41	52
24	3612192	NARAYANAN. S	20	Male	RE	6/24p	47	51.1	56.2	4.2	418	21	36	6/24p	47	51.2	56.7	4.1	416	26	44

25	2542062	MARIYAM SYED			LE	6/9	47.1	48.7	51.1	1.5	510	9	30	6/9p	46.5	48.8	53.2	2.3	503	16	50
25	2542062	MARIYAM SYED	21	Male	RE	6/12	50.5	55.7	64.6	5.2	456	43	81	6/12p	55.5	59.9	66.8	4.4	413	48	100
26	2108022	ROHIT			LE	6/6p	41.4	45.8	46	4.4	503	30	40	6/6p	41.6	45.7	46.4	4.1	504	28	37
26	2108022	ROHIT	11	Male	RE	6/6p	41.7	46	46.2	4.4	508	29	36	6/6p	41.7	45.8	46.1	4.1	504	26	35
27	3621487	BEJOY			LE	6/24	45.1	48.7	57.3	3.6	493	34	76	6/24	49.7	55.4	64.2	5.7	454	51	96
27	3621487	BEJOY	13	Male	RE	6/60	52.6	59.9	69.4	7.3	451	51	98	4/60	67.6	73.5	78.6	5.9	433	66	140
28	3064058	PONDEVI			LE	6/9	56.9	65	69.7	8.1	387	40	83	6/12	60	69.6	80	9.6	357	54	105
28	3064058	PONDEVI	13	Female	RE	6/12	55.4	62.7	65.7	7.2	378	43	99	6/12p	53.7	61.6	63.3	7.8	330	44	103
29	3600208	PANDI.V			LE	6/60	54.8	58.1	62	3.2	352	47	54	4/60	47	55	56.2	4.7	400	28	36
29	3600208	PANDI.V	12	Male	RE	6/9	46.3	50.9	53.7	4.6	447	47	62	6/9p	49	53.8	57.2	4.8	398	25	41
30	3639036	SUGANYA.V			LE	6/9p	54	62	70	8	373	43	80	6/60	50.8	59.6	63.8	8.8	324	35	94
30	3639036	SUGANYA.V	22	Female	RE	6/12	48.5	55.2	61.6	6.7	408	23	47	6/24	48.2	55.2	61.6	7	404	25	48
31	3640400	SHEETU.A			LE	6/6	44.8	46.8	48.7	2.1	474	7	25	6/6	44.7	46.9	49.2	2.2	484	9	18
31	3640400	SHEETU.A	23	Female	RE	6/18	50	55.5	63.9	5.4	441	29	53	6/12	49.7	54.7	63.1	5	439	26	49
32	3358339	RAJARAMAN			LE	6/24p	55.1	60.4	64.9	5.3	399	35	92	6/24p	54.4	59.4	62.6	5	362	37	74
32	3358339	RAJARAMAN	14	Male	RE	6/12p	52.8	56.3	60.4	3.5	416	30	68	6/12p	53.9	57.1	61.4	3.2	418	36	78
33	3529127	SATHYABAMA			LE	6/9	45.8	48.5	52.2	2.7	479	22	59	6/9	48.5	45.3	52.3	3.3	473	23	29
33	3529127	SATHYABAMA	21	Female	RE	6/9	47	50.7	53.8	3.7	475	24	51	6/9	47.1	50.6	53.9	3.5	464	23	49

34	3659343	JITHIN VARGHESE			LE	6/12	43.2	47.9	55.9	4.6	539	24	54	6/9p	45.9	49.8	58.6	3.9	533	28	65
34	3659343	JITHIN VARGHESE	15	Male	RE	6/12	48.4	51.8	59.8	3.4	512	29	67	6/6	51.1	54.1	62	3	503	32	85
35	3600681	SHAIK MD SHAFI			LE	6/9p	55.5	56.6	68.1	1.1	442	40	80	6/12	59.1	56.8	68	2.3	433	54	103
35	3600681	SHAIK MD SHAFI	16	Male	RE	6/9p	62.2	66.3	74.9	4.1	397	62	135	6/18	62.2	66.3	74.9	4.1	397	62	135
36	3667682	ABINAYA			LE	6/9	56.3	59.6	70.8	3.3	423	40	83	6/12p	53.6	55.8	64.9	2.2	402	27	65
36	3667682	ABINAYA	16	Female	RE	6/9	50.6	54.6	59.9	4.1	468	21	47	6/9	50	53.4	60.8	3.4	468	25	53
37	3668549	AKASH RAM			LE	6/6	43.2	45.1	45.8	1.9	492	8	32	6/6	43.4	45.1	46.1	1.7	485	6	19
37	3668549	AKASH RAM	18	Male	RE	6/12p	45.2	52.4	55.9	7.1	457	29	54	6/12p	44.4	51.8	56.6	7.4	397	31	43
38	2710948	VISHNU BARATHI			LE	6/24	53.9	61.6	70.2	7.7	436	50	93	6/24p	55.1	62.1	69.5	7	420	50	103
38	2710948	VISHNU BARATHI	14	Male	RE	6/12	50.9	55	64.9	4.1	457	29	59	6/12p	53.7	57.9	67	4.2	455	35	69
39	3674938	SANKAR.K			LE	6/6	44.9	46.3	48.7	1.4	493	10	23	6/6	45.1	46.3	48.8	1.3	493	10	21
39	3674938	SANKAR.K	22	Male	RE	6/6	45.9	50.1	55.7	4.2	462	29	54	6/6p	46.3	50.2	56	3.9	454	30	53
40	3534510	YASWANTH.S			LE	6/18p	49.1	55.5	58.8	6.4	472	32	66	6/24p	49.8	58.3	64.3	8.5	460	35	65
40	3534510	YASWANTH.S	14	Male	RE	6/60	63.1	61.3	70	1.8	384	32	115	6/60	62.5	61.5	72.8	1	333	36	120
41	3677910	HABIN.S			LE	6/6	45	46.3	48.7	1.3	476	11	17	6/6	45.5	47.1	49.6	1.6	465	11	21
41	3677910	HABIN.S	16	Male	RE	6/9	51.4	54.6	60.9	3.2	422	26	57	6/36	52.7	55.9	61.3	3.2	418	20	43
42	3677995	NAGARAJAN.R			LE	6/6	46.5	47.1	47.9	0.6	482	5	13	6/6	46.7	47.2	48	0.5	484	5	12
42	3677995	NAGARAJAN.R	24	Male	RE	6/6p	47.2	51.1	54.1	3.9	464	12	29	6/9	47.4	51.5	54.8	4.1	469	14	30

43	3678906	JITHUMON SHAJI			LE	6/6p	45.8	53	61.8	7.1	464	27	51	6/9p	46.3	52.8	61.9	6.5	468	31	51
43	3678906	JITHUMON SHAJI	18	Male	RE	6/6	43.1	43.8	44.9	0.7	505	5	14	6/6	43.5	44.3	45.4	0.9	499	7	14
44	3691539	TONY THOMAS			LE	6/9	45.9	49.5	55.9	3.6	442	22	45	6/9p	48.6	51	60.2	2.4	420	34	56
44	3691539	TONY THOMAS	16	Male	RE	6/6p	42.9	44.6	47.9	1.7	465	12	28	6/6	43.3	45.2	49	1.9	452	15	30
45	3396828	OAM PRASATH			LE	6/18p	44.8	53.5	59.2	8.7	470	27	47	6/24	44.7	54.8	61.1	10.1	468	33	52
45	3396828	OAM PRASATH	21	Male	RE	6/6p	44	47	50.2	3	479	12	19	6/6p	44.2	48.1	51.5	3.8	466	14	27
46	3572375	HARINI			LE	6/12p	43.9	48.4	49.5	4.5	458	28	26	6/6p	43.9	48.1	48.7	4.2	481	28	35
46	3572375	HARINI	16	Female	RE	6/12p	43.8	48.7	49.2	5	497	31	36	6/9p	43.8	48.7	49.4	4.8	480	30	37
47	3706138	MADHUSUGANYA			LE	6/9	50.1	52.8	56.6	2.8	410	33	62	6/9p	50	53.4	58.1	3.4	414	37	62
47	3706138	MADHUSUGANYA	18	Female	RE	6/9	49.1	52.9	56.8	3.7	409	31	43	6/9p	49.5	52.8	57.1	5.9	359	31	51
48	3307931	RAJASEKAR			LE	6/9	49	46.2	50.4	2.8	518	34	68	6/12	49.1	45.9	50.7	3.2	531	37	63
48	3307931	RAJASEKAR	21	Male	RE	6/18p	50.2	46	51.8	4.3	510	44	78	6/24	50.2	45.5	51.7	4.7	513	44	91
49	3715803	NISHA.K			LE	6/24	52	56.3	64.7	4.3	411	34	59	6/24p	51.4	54.5	64.1	3	360	36	65
49	3715803	NISHA.K	18	Female	RE	6/12	43.8	47	55.1	3.3	441	22	41	6/12	44.6	47.9	57.1	3.3	446	23	37
50	3722680	SHIJO.A			LE	6/18p	47.4	54.6	63.6	7.3	515	37	79	6/24	48	55.1	64.7	7.2	502	39	83
50	3722680	SHIJO.A	24	Male	RE	5/60	64.5	69.6	82.4	5.1	401	75	178	4/60	64.1	69	80.8	4.9	321	74	166
51	3725268	SYED ALI FATHIMA			LE	6/9p	50.6	49.5	55	1.1	405	30	50	6/9p	49.7	51.1	55.8	1.3	409	32	52
51	3725268	SYED ALI FATHIMA	22	Female	RE	6/6p	47.8	50.1	53.7	2.3	406	26	49	6/6p	48.6	51.4	54.1	2.8	419	21	42

52	3728520	DHARUN.M			LE	6/24p	47.1	52.9	58	5.8	463	20	49	6/18	46.9	54.9	62	8	455	27	56
52	3728520	DHARUN.M	11	Male	RE	6/18	49.6	58.3	62.8	8.7	433	44	88	6/36	51.1	59.9	65.7	8.9	429	38	73
53	3752445	SAEED AISHATH			LE	6/9	49.6	45.5	54.5	4	489	39	70	6/9p	50.8	46.6	56.6	4.2	484	42	76
53	3752445	SAEED AISHATH	25	Female	RE	6/9	43.8	45.3	47.3	1.5	516	9	19	6/9	43.7	45.3	47.6	1.6	517	10	23
54	3753488	IFTHIQUAR AHMED			LE	6/9	49.4	53.2	58.9	3.8	471	39	62	6/12p	50.5	53.3	58.6	2.8	463	32	60
54	3753488	IFTHIQUAR AHMED	11	Male	RE	6/6p	44.9	47.8	51.6	2.9	498	12	19	6/9	45.4	48.3	51.9	2.9	494	14	26
55	3756301	ARUN THOMAS			LE	6/12p	43.8	48.8	54.9	5	436	36	73	6/12	44	48.4	55.3	4.4	444	37	75
55	3756301	ARUN THOMAS	14	Male	RE	6/6	43.8	40.9	49.8	2.9	463	27	56	6/6	41.7	44.8	51	3.1	459	28	61
56	3748120	SAMEERA BEGAM			LE	6/18p	56	50.3	63.2	5.7	428	31	49	6/18	55.3	51	60.4	4.3	369	29	57
56	3748120	SAMEERA BEGAM	11	Female	RE	6/12p	53.8	51	60.8	2.8	438	34	55	6/18	54.8	58.6	69.9	3.7	396	48	73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EVALUATION OF PROGRESSION OF KERATOCONUS USING PENTACAM

DISSERTATION SUBMITTED FOR

MS (Branch III) Ophthalmology

THE TAMILNADU DR. M.G.R MEDICAL UNIVERSITY CHENNAI

APRIL – 2015